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Review of Motorcycle Brake Standards

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Preface

This report constitutes a partial deliverable for the Call No. 01 of Standing Offer Agreement T8080-011547/001/SS entitled "Motorcycle Brake Test – Comparison of Standards and Test Assistance". All motorcycle testing was conducted in accordance with existing test procedures and may not reflect the maximum performance of the motorcycles in the test program.

Executive Summary

In a joint research program between the U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA) and the Road Safety and Motor Vehicle Regulation Directorate, Transport Canada (TC) three regulations for motorcycle brake systems were compared to assess the relative level of test severity. The regulations were the Federal Motor Vehicle Safety Standard (FMVSS) No. 122, the Economic Commission for Europe (ECE) Regulation No. 78 and the Japan Safety Standard (JSS) J12-61.

A paper review compared each section of the respective regulations. Five motorcycles were then tested to the protocols of each of these standards. To assess the effectiveness of anti-lock braking systems (ABS), additional testing with motorcycles equipped with ABS was conducted in accordance with a proposed test method provided by Transport Canada.

Summary tables of the motorcycle braking test results are provided along with the respective test margin of compliance (MOC). The MOC is a dimensionless quantity which served to gauge the extent to which the motorcycles passed or failed specified performance requirements. Based on these results, it was found that the FMVSS test method for the "dry" braking test, and the ECE methods for the fade and recovery and the wet brake tests were the most difficult protocols to meet.

Despite these results, the MOC does not provide sufficient means to determine which protocol, or portion thereof, is the most appropriate for evaluating motorcycle brakes. For example, many of the ECE and JSS procedures test each brake system independently. While this method may be more severe, it may not reflect normal driving practice.

Wet brake performance is also evaluated quite differently between the national regulations. The ECE and JSS protocols are likened to braking while driving in the rain whereas the FMVSS measures wet brake recovery following the crossing of a ford. The later test applies to all motorcycle brakes whereas drum brakes and waterproof disc brakes are exempt from the ECE and JSS standards. Additional investigation into the necessity and relevance of the respective protocols is needed, in view of selecting the most appropriate protocol for evaluating motorcycle brake systems.

With regards to the effectiveness of ABS brakes, the test results generally demonstrated reduced stopping distances with the ABS enabled, while braking on dry asphalt. Further testing would demonstrate the influence that motorcycle type or rider confidence may have on braking performance.

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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) conducted a joint research program to compare the levels of stringency of three regulations for testing motorcycle brake systems. The three evaluated regulations were the Federal Motor Vehicle Safety Standard (FMVSS) No. 122, the Economic Commission for Europe (ECE) Regulation No. 78 and the Japan Safety Standard (JSS) J12-61. A paper review was completed that included a detailed comparison of the test requirements and compliance severity. Five motorcycles were tested to the protocols of each of the three standards and the results were compared by method of margin of compliance to assess test severity. An additional test procedure was proposed by Transport Canada to assess the effectiveness of anti-lock braking systems (ABS) when used on motorcycles.

2. Test Procedures

2.1 Brake System Regulations

Five motorcycles were tested according to the procedures of three different regulations, FMVSS 122, ECE Reg. No. 78 and JSS 12-61. The test protocols and performance requirements for each are summarized in Appendix A. The following is a brief description of the test protocol of each regulation.

2.1.1 FMVSS 122 Motorcycle Brake Systems

The purpose of the FMVSS 122 standard for motorcycle brake systems is to ensure sufficient performance for braking during both normal and high-speed situations. To accomplish this, the standard requires a motorcycle to be able to stop within a specified distance from several initial speeds and under various test conditions.

A series of tests are conducted that include an initial effectiveness test, a burnish procedure, a second effectiveness test, a fade-and-recovery test, a final effectiveness test and a water recovery test. Typically, the tests are conducted with the motorcycle in an unladen configuration with both brakes applied (the laden, or unladen condition describes the test weight of the motorcycle and is specified in the regulation). This test configuration is used in the second and final effectiveness tests, the fade and recovery test, and the water recovery test. Some tests, like the first effectiveness tests, require each brake system to be tested independently. The number of stops for each test and the speeds from which the stops are made are clearly stated and at least one stop must be made within the specified distance to comply with the requirement. The Canadian brake testing standard, the CMVSS 122, is functionally identical to the FMVSS 122. The test center at PMG Technologies conducted the FMVSS testing using their existing protocols for the CMVSS.

2.1.2 ECE Regulation No. 78

The overall approach to motorcycle brake performance is addressed by the ECE Reg. No. 78 in a similar manner to that of the FMVSS 122 standard. A series of tests are presented, under various conditions, and the motorcycle must meet certain performance requirements. However, there are numerous differences with respect to the test protocols and the way braking performance is measured.

Contrary to the FMVSS, the ECE regulation requires that the motorcycle be tested in the fully laden and unladen conditions, and that each brake system, front and rear, is tested individually and also simultaneously. Furthermore, where the FMVSS performance is based on stopping distances, the ECE regulation includes provisions for using the mean fully developed deceleration (MFDD) as an alternative. The MFDD is defined in the ECE regulation as the vehicle deceleration calculated between 10 and 80 percent of the vehicle initial speed.

Contrary to the FMVSS and the JSS, the ECE regulation does not include specific braking performance requirements for speeds greater than 100 km/h. Instead, the maximum practical performance is measured and the vehicle behavior is recorded to the lower of 160 km/h or 80 percent of the vehicle maximum speed.

Unique to the JSS and ECE regulations are a series of tests specific to motorcycles equipped with an ABS package. Although there is no requirement to include ABS, there are provisions to test a motorcycle if it is so equipped. In this case, the motorcycle is tested in the unladen condition. The performance tests in the ECE regulation consist of individual and simultaneous application of the brakes from a specified speed, under which no wheel must lock. The tests are performed on two road surfaces, high-adhesion and low-adhesion, and include constant road surface testing as well as tests while the motorcycle crosses from one road surface onto another (low-adhesion to high-adhesion and vice-versa). All braking tests are conducted with the motorcycle traveling on a straight course.

2.1.3 Japanese Safety Standard 12-61

The test procedures described in the JSS 12-61 are very similar to those in the ECE Reg. No. 78. In fact, the JSS 12-61 lists the ECE regulation as an example of an equivalent standard. The braking tests for fade and recovery, and the wet brake tests are identical whereas small variances exist in the dry stop tests such as the total number of stops and performance requirements for stops from speeds above 100 km/h. While both regulations include specific provisions for the testing of ABS-equipped motorcycles, the ECE regulation demands additional ABS tests.

Both the ECE and JSS allow the use of stopping distance or mean deceleration as a measure of braking performance, and in most cases the performance requirements are the same. With respect to mean deceleration, the JSS gauges performance based on vehicle mean saturated deceleration (MSD). The purpose of utilizing the MSD or the MFDD (per the ECE requirement) is to isolate the actual motorcycle deceleration performance by excluding the effect of driver reaction at the beginning and end of a braking maneuver. Unlike the ECE prescribed method to calculate the MFDD, the MSD can be obtained several ways depending on the method employed to measure vehicle deceleration. The different methods employed can provide slightly different results.

In order to maintain consistency in the results, whether testing to the requirements of the ECE or the JSS, an alternate method was utilized to calculate the vehicle deceleration based on the same principles used to calculate MFDD and MSD. This was achieved by way of a logical gate that determines the best fit curve for the vehicle deceleration, thus isolating the motorcycle braking performance from variables such as the rider's reaction time. The deceleration results are referenced as the vehicle MFDD throughout the report.

2.2 Differences Among Regulations

Several differences exist between the three national test standards mentioned above, in both the test method and performance requirements. For example, where the ECE and JSS test methods allow the use of either the MFDD or the stopping distance to measure the brake performance, the FMVSS standard evaluates only the stopping distance. Also, the ECE and JSS regulations include additional performance requirements for motorcycles equipped with ABS while the FMVSS protocol does not.

In general, the FMVSS test method requires that the vehicle be unladen, the front and rear brakes be applied simultaneously and the engine be disconnected during braking maneuvers. The ECE and JSS test methods are similar, but also include performance requirements for a fully laden vehicle, which generally means that additional weight is added until the total weight of the motorcycle and rider is equal to the maximum vehicle design weight. Furthermore, the respective front and rear brakes are tested independently and then simultaneously, and tests are also conducted with and without the engine connected. With the engine connected, engine braking occurs, whereby the engine friction and the gearing of the transmission aid in slowing the motorcycle.

Unique to the FMVSS standard is the brake burnishing requirement, which is a procedure to condition the surface of new brake pads through initial wear. The first effectiveness (or pre-burnish) test is followed by a 200-stop burnish procedure. The second performance evaluation is then conducted followed by the fade and recovery test. A re-burnish procedure is done before the completion of the final effectiveness and the water recovery tests.

The FMVSS test protocol approaches the water recovery test very differently than the ECE and JSS protocols. The FMVSS requires the brake components to be fully immersed in water only once, at the beginning of the stopping sequence. This soaking procedure can be likened to riding through a river. Braking performance is then measured during the fifth recovery stop. This test is applicable to all types of motorcycle brakes, including the drum brakes as the immersion process is expected to cause water to penetrate the drum case.

By comparison, the ECE and JSS share a common procedure which is likened to braking while driving in the rain. Unlike the FMVSS recovery test, the braking performance is evaluated while water is continuously sprayed onto the brakes. This test applies to brake systems other than waterproof disc brakes and conventional drum brakes which are not subject to water penetration under normal running conditions, as the spray will not affect braking performance.

2.3 ABS Effectiveness Test Procedures

The ECE and JSS standards include performance requirements for motorcycles equipped with the ABS and/or Combined Braking System (CBS), but the FMVSS standard does not. The ABS automatically controls the amount of wheel slip on one or more of the vehicle wheels during braking. The CBS allows the activation of both the front and rear brakes through the application of either the hand lever or the foot pedal. The ECE and JSS standards assure a minimum level of performance for ABS and/or CBS equipped vehicles.

In order to gain some insight into the effectiveness of ABS, specific test procedures were developed by Transport Canada to evaluate the performance of motorcycles equipped with ABS as compared to motorcycles without ABS. Three tests were introduced that include braking the motorcycle to a stop while traveling in a straight line on wet and dry road surfaces, and braking to a stop while following a curved path on a dry road surface. In order to evaluate performances, ABS equipped motorcycles underwent each test with the ABS fully enabled and then with the ABS fully disabled. The proposed test procedure, as provided by Transport Canada, is presented in Appendix E.

3. Test Protocol

3.1 Purpose and Scope

The purpose of the motorcycle testing is to compare the relative level of test severity of three national motorcycle brake standards. This evaluation considers only the results of one regulation versus the results of another. It is not an evaluation of the relevance or suitability of the respective test protocols or performance requirements.

The test protocols within the respective standards are not designed to assess the maximum performance of a motorcycle's braking system, rather they are designed to assure a minimum level of performance. The respective test protocols were performed and evaluated in this way. For example, the allowable force applied to the hand lever or foot pedal during a stop is normally limited within a specific range. The actual stopping distance or MFDD obtained during the test can vary depending on whether the applied brake force is near the top or bottom of the allowable range. Once the test was passed, there was no need to increase the applied brake force to determine to what extent the pass/fail criteria can be exceeded.

Each motorcycle was tested in accordance with the requirements of the standard, as if undergoing a normal compliance evaluation. The level of severity between one standard and another was dependant on the degree of difficulty with which the motorcycle passed or failed the test. A measure of the extent to which a particular motorcycle passed or failed the performance requirement was obtained by calculating the margin of compliance (MOC), discussed in the following section.

In addition to the variability within the regulations, additional variables were introduced in the form of rider input and motorcycle type. Five motorcycles and three test riders were used throughout the test series. It is intended that the average response of all the input conditions will identify trends to suggest which, if any, test protocol is more severe.

3.2 Method of Margin of Compliance

The method of margin of compliance (MOC) was selected to evaluate the different tests within the respective standards because it can provide an immediate sense of test severity, independently of the specific test protocol and performance (i.e. pass/fail) criteria.

The MOC is a calculated value defined as the ratio of a measured value with respect to a target value. In the case of assessing braking distances, the MOC would be calculated by dividing the maximum allowable stopping distance by the actual stopping distance. An MOC greater or equal to 1.0 means that a pass was achieved; the higher the value, the easier the protocol's pass/fail criteria was attained. Values less than 1.0 indicate a failure to meet the pass/fail criteria.

The test protocols and performance criteria vary from one standard to the next, and would require in-depth analysis to determine their relative effect within each standard. It is not possible to determine which protocol is best suited to evaluate motorcycle brakes based on the MOC alone. Some of the variables affecting performance include the vehicle test weight, the allowable brake lever and brake pedal force, the allowance for engine braking and braking from different test speeds. Additional investigation is necessary to evaluate the relevance and appropriateness of the respective tests.

4. Test Motorcycles

Vehicle testing was conducted by PMG Test and Research Centre in Blainville, Quebec, Canada between October 2002 and May 2003. PMG was responsible for the acquisition, preparation and testing of all motorcycles. PMG also provided the necessary test drivers, safety equipment and instrumentation.

4.1 Motorcycle Descriptions

Five motorcycles were selected for inclusion in this test series and each is listed in Table 1. The motorcycles were selected to represent a variety of styles while providing a sufficient number of motorcycles equipped with ABS.

Table 1: Motorcycle List

Year	Make	Model	VIN
2002	Honda	Interceptor VFR800	JH2RC46542M400140
2002	Honda	ST1100A	JH2SC26502M200006
2002	Suzuki	Marauder GZ 250	VTTNJ48A922100304
2003	Harley Davidson	Dyna Super Glide FXD	5HD1GHV113K300050
2001	BMW	C1 Executive 125	WB10191A914A17898

A description of each motorcycle follows, including a brief summary of the respective brake systems, 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.

4.1.1 Honda VFR800

A sport touring motorcycle aims to balance the comfort and convenience of a touring bike with the style and performance of a sport-bike. The Honda VFR800 Interceptor represents a sportier model available in this category as shown in Figure 1. This motorcycle is equipped with Honda's Linked Braking System (LBS) as well as the optional ABS.

Figure 1: Honda VFR800

The LBS allows both brakes, front and rear, to be activated with either the hand or the foot lever. 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 2: Honda VFR Manufacturer's Specifications

Front Brake	Dual 296 mm discs with LBS-ABS three-piston calipers
Rear Brake	Single 256 mm disc with LBS-ABS three-piston caliper
Engine	781 cc 90-degree V-4
Dry Weight	219 kg
Gross Vehicle Weight	432 kg

4.1.2 Honda ST1100A

The Honda ST1100A, Figure 2, tends towards the touring side of the sport-touring category. This motorcycle comes standard equipped with Honda's LBS as well as ABS. Coupled with the ABS, a traction-control system also keeps the rear wheel from slipping during acceleration.

Figure 2: Honda ST1100A

The LBS functions similarly to the LBS described for the VFR800, where each control operates a portion of both the front and rear brakes. The ABS features a modulator designed to adjust braking pressure to minimize wheel lockup during hard braking on low-traction road surfaces. The brake system is also designed to prevent complete loss of braking in case of a system component failure. The traction control is accomplished by using the wheel-speed sensors of the ABS to prevent excessive rear-wheel slippage during hard acceleration on low-traction road surfaces.

Table 3: Honda ST1100 Manufacturer's Specifications

Front Brake	Dual 296 mm discs with LBS-ABS three-piston calipers
Rear Brake	Single 296 mm disc with LBS-ABS three-piston caliper
Engine	1085 cc 90-degree Transverse V-4
Dry Weight	297 kg
Gross Vehicle Weight	508 kg

4.1.3 Suzuki GZ250

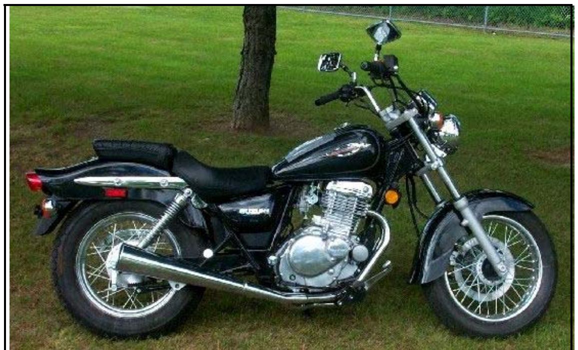

Figure 3: Suzuki GZ250

The styling, low chassis and raked-out fork design places this motorcycle in the category of the cruisers, although the Suzuki Marauder GZ250 is one of the smaller motorcycles in the test line-up. The GZ250 is pictured in Figure 3. The brake system on this motorcycle consists of a front disc and rear drum. This configuration represents a basic brake system set-up in comparison to the other motorcycles tested.

Table 4: Suzuki GZ250 Manufacturer's Specifications

Front Brake	Single Disc, hydraulically operated
Rear Brake	Drum, mechanically operated
Engine	249 cc single-cylinder
Dry Weight	137 kg
Gross Vehicle Weight	238 kg

4.1.4 Harley Davidson FXD

Figure 4: Harley Davidson FXD

The Harley Davidson FXD Dyna Super Glide, see Figure 4, is another motorcycle from the cruiser category but this cruiser is much bigger than the Suzuki Marauder. The Harley Davidson has a higher gross vehicle weight and the Twin Cam 88® engine is the largest displacement engine of the motorcycles in this test line-up. The brakes on the Dyna consist of a single disc brake in the front and back and both are equipped with a 4-piston caliper. Other models of the Dyna motorcycle, like the Sport and T-Sport, are offered with dual front discs instead of the single disc.

Table 5: Harley Davidson FXD Manufacturer's Specifications

Front Brake	Single 292 mm disc with a 4-piston caliper
Rear Brake	Single 292 mm disc with a 4-piston caliper
Engine	1450 cc V-twin
Dry Weight	287 kg
Gross Vehicle Weight	502 kg

4.1.5 BMW C1 Executive

The BMW C1 has a small displacement engine, an upright seating position and a step-through chassis design making it very different from the other motorcycles in this test series. It is also the only motorcycle tested here that has a roof with a rigid occupant compartment offering enhanced weather shielding, impact protection and seatbelts (see Figure 5). The brake system consists of single discs, front and back, and ABS. Many of the other motorcycle models offered by BMW are also available with ABS.


Figure 5: BMW C1 Executive

Due to the design of the occupant compartment, the laws requiring helmet use for such a vehicle vary with the countries in which this motorcycle is sold. As the C1 is not available for purchase in North America, a European model was used. Of interest was to review how a European legal motorcycle (i.e. meeting the ECE regulations) would perform in these tests.

Table 6: BMW C1 Manufacturer's Specifications

Front Brake	Single 220 mm disc, ABS and two-piston, full-floating caliper
Rear Brake	Single 220 mm disc, ABS and single-piston, full-floating caliper
Engine	125 cc single
Dry Weight	185 kg
Gross Vehicle Weight	360 kg

4.2 Vehicle Preparation

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. New brake pads and rotors were installed prior to testing to each standard. When the threat of tipping the motorcycle was higher, additional protection was added to the vehicle to prevent damage to the motorcycle (see Figure 6).

Figure 6: Motorcycle Set-up

Some tests required the motorcycle to be heavily laden. This made the motorcycle difficult to handle due to the extra weight required. For operator safety and improved bike handling, a larger test driver was used which reduced the required ballast.

5. Test Description and Results

This section includes a summary of results that have been computed using the test data provided by PMG. A more detailed summary of the test results is available in the appendices of this report. A brief description of the test conditions is provided where suitable. For further details on the test procedures, please refer to the regulation comparison summary in Appendix A or to the appropriate regulation.

5.1 Summary of Results

Testing was completed on all five motorcycles. The MOC was computed for each test on each motorcycle to better compare the severity of one test standard to another. As explained in Section 3.2, an MOC equal or greater than 1.0 indicates a pass while an MOC of less than 1.0 is considered a failure. The higher the value, the easier the protocol's pass/fail criteria was attained. For tests that allowed alternate pass/fail criteria, e.g. performance criteria based on stopping distance or deceleration, the margin of compliance was computed for each criteria.

Combining data from all motorcycle tests, the minimum, maximum, standard deviation and average MOC were computed and are presented in Table 7. The test results from each procedure have been included regardless of the laden condition, the speed of the test or the braking method (i.e. individual versus simultaneous application of the brakes). The lowest average MOC for each of the dry, wet and fade procedures is highlighted in gray shading, indicating that these procedures and performance requirements were achieved with a higher degree of difficulty. Additional data from each test series can be found in the appendices of this report.

Based on the data in Table 7, the FMVSS test method for the "dry" braking test, and the ECE methods for the fade and recovery and the wet brake tests were the most difficult protocols to meet. The JSS and ECE results were very similar (equal with respect to the fade test), sharing most protocols and performance requirements. However, the MOC data does not provide sufficient means to determine which protocol, or portion thereof, is the most appropriate for evaluating motorcycle brakes. Additional investigation into the necessity and relevance of the respective protocols is needed, in view of selecting the most appropriate for evaluating motorcycle brake systems.

Table 7: Margin of Compliance Summary

Test Procedure		Margin of Compliance (MOC)			
		Minimum	Maximum	Standard Deviation	Average
Dry	FMVSS Distance	1.05	1.61	0.14	1.32
	ECE Distance	1.01	2.14	0.44	1.54
	ECE MFDD	0.92	2.28	0.40	1.56
	JSS Distance	1.20	2.32	0.37	1.51
	JSS MFDD	1.00	2.07	0.33	1.47
Wet	FMVSS Distance	1.42	4.83	1.23	2.76
	ECE MFDD (0.5-1.0)	1.27	2.40	0.38	1.74
	ECE Decel. (Max)	1.12	1.54	0.15	1.24
	JSS MFDD (0.5-1.0)	1.31	1.97	0.22	1.51
	JSS Decel. (Max)	1.13	1.90	0.24	1.42
Fade	FMVSS Distance	1.67	4.66	1.16	3.06
	ECE Distance	1.03	1.60	0.22	1.34
	ECE MFDD	0.96	2.03	0.35	1.45
	JSS Distance	0.90	2.04	0.32	1.34
	JSS MFDD	0.97	2.15	0.38	1.48

The individual motorcycle average MOC results were consistent with those in Table 7. With respect to the wet and fade tests, either the JSS or the ECE requirements were consistently the most difficult to achieve. With respect to the dry test, the FMVSS was the most difficult to achieve, with the exception of the Suzuki GZ250 which exhibited greater difficulty passing the ECE regulation. The combination of operator control and motorcycle type, including brake system and tire type, were factors which caused variations between the results.

Difficulties encountered while testing included trying to achieve the proper brake temperature specified in the FMVSS, on motorcycles equipped with CBS. For the dry tests, the standard requires a brake temperature between the narrow range of 54.4 to 65.5 degrees Celsius before each stop. It was difficult to obtain temperatures within this narrow range at each brake, as the application of the brake pedal or brake lever would activate both brakes. This was not a problem with the JSS or ECE regulations, which required an initial brake temperature of less than 100 degrees Celsius.

The motorcycles were equipped with the original tires recommended by the manufacturers. The effect of different tire types on braking performance was not evaluated in these tests. All motorcycles benefited from new tires prior to testing to each regulation, with the exception of the BMW C-1. Replacement tires were not available for the BMW C-1, such that all testing was conducted on a single set of tires. Therefore, the results from the BMW C1 have not been included in the comparison of the national regulations. The performance data is available in the appendices, for reference.

Due to a misinterpretation of the text, the laden motorcycles tested to the JSS protocol were loaded in excess of the intended laden weight, by as much as 60 kg. The effect of this additional weight likely exacerbated the stopping performance of the motorcycles. Despite this condition, the JSS procedures were not necessarily found to be the most difficult to meet, which reflects favorably on the capability of some of these braking systems. All laden data acquired while testing to the JSS requirements are included and comments to that effect accompany the analysis, where applicable.

5.2 Dry Tests

All three standards utilize braking distance as a performance criteria which must be met in order to successfully pass the dry tests. For a given speed, under specific conditions, the motorcycle must be stopped within a specified distance. In addition, the ECE and JSS standards both offer the alternative criteria of meeting or exceeding a minimum required MFDD. In those cases, the motorcycle need only meet one of either criteria in order to pass the given test.

The MOC was calculated for the stopping distance and, where applicable, the MFDD of each test. For the stopping distance, the MOC is calculated by dividing the maximum allowable stopping distance by the measured stopping distance. For the deceleration criteria, the MOC is obtained by dividing the measured MFDD by the minimum required MFDD.

The average MOC results were very close to one-another, ranging from 1.32 to 1.56 (see Table 7). The FMVSS exhibited the lowest average MOC for the dry tests, which indicates that the performance criteria therein were more difficult to achieve than with other national protocols. The minimum MOC value listed in Table 7 is below 1.0, indicating that at least one motorcycle failed the ECE requirement based on the deceleration criteria.

Unlike the FMVSS and JSS protocols, the ECE does not include braking performance requirements from speeds greater than 60 km/h, rather only the vehicle behavior is recorded. The ECE and JSS share the same protocols with the exception that the JSS tests includes performance requirements for a high speed test. The MOC results for the high speed test (see Appendix B: General Test Results) were not significantly different than the overall average, indicating that this additional test did not have much effect on the results in Table 7.

The JSS high speed test was conducted with engine braking, which can assist in decelerating the vehicle depending on the amount of engine friction and the selected gear at the time of braking. The effect of engine braking was not measured, however, the respective motorcycle transmission was in the required highest gear during this test, which would provide the least braking assistance of any selected gear. Further testing would be required to determine the extent of assistance provided by engine braking. The engine was disconnected in the FMVSS "high speed" test (i.e. no deceleration assistance from engine braking).

The JSS average MOC results are slightly lower compared to the ECE, indicating that the protocol requirements were slightly more difficult to achieve. In addition, the JSS results were achieved with the laden motorcycles being tested beyond the intended test weight, which likely exaggerated the severity of this test. Overall, despite testing overloaded motorcycles to the JSS protocol, the FMVSS protocol was found to be the most difficult to achieve.

The JSS high speed test assures minimum braking performance from 80 percent of the vehicle maximum speed, not exceeding 160 km/h. The FMVSS includes minimum braking performance for motorcycle speeds up to 192 km/h. No tests were conducted above a speed of 160 km/h, as the benefits do not seem to warrant the potential hazard to which the test rider is exposed.

5.3 Wet Brake Tests

Following the complete immersion of the front and rear brakes, five water recovery tests for the FMVSS procedure are performed from an initial speed of 48.3 km/h. The test requirement is that the maximum brake lever or pedal force during the fifth recovery stop is no more than 89 N above and no less than 45 N below the average force determined in baseline tests conducted in dry conditions. Both brakes are applied during the tests. In this instance, the MOC is obtained by dividing the maximum allowable brake force by the maximum measured force in the fifth recovery stop.

The ECE and JSS share wet braking test procedures. The brakes are soaked with a continuous spray of water during the tests, and the front and rear brakes are tested separately from an initial speed of 60 km/h. For the wet test, the mean deceleration attained 0.5 to 1.0 second after brake application must be at least 60% of that measured in a baseline test conducted in dry conditions, with the same brake application force. In addition, the maximum deceleration must not exceed 120% of that attained in the baseline test. The MOC has been determined for both these criteria. Unlike the FMVSS, the ECE and JSS procedures do not apply to drum brakes or waterproof disc brakes.

The average MOC results in Table 7 indicate that it was more difficult to pass the ECE and JSS requirements. The FMVSS average MOC is nearly double that of the other tests, and the minimum and maximum values are also higher. As with the dry tests, the severity of the JSS results are likely exaggerated due to the motorcycle being overloaded during the tests.

With the exception of testing the JSS standard with an overloaded motorcycle, the ECE and JSS testing procedures are the same. Therefore, with an overloaded motorcycle, it would be expected that the required performance level would be more difficult to achieve. Despite this weight difference, the performance with the overloaded motorcycle was better in some cases, which reflects positively on the respective brake systems.

As a reminder, the motorcycle brake systems were not tested to their maximum performance capability, rather they were tested to pass the minimum requirements of the standard. A different (i.e. heavier) test rider was used for testing to the JSS requirements to compensate for the additional ballast required, and may have been more aggressive with the brakes than the operator testing to the ECE requirements. Different results could be expected had the brake systems been tested to the limits of performance.

5.4 Fade and Recovery Tests

As with the water recovery test, the FMVSS procedure for fade and recovery begins with baseline measurements of the brake forces necessary to maintain a deceleration of 3.04 to 3.34 m/s^2. Fade stops are then conducted at 96.6 km/h and consist of 10 stops with a deceleration rate of 4.56 m/s^2. Finally, five recovery stops are made from 48.3 km/h while maintaining the same deceleration as in the baseline stops. The pass/fail result is determined during the fifth recovery stop, whereby the test requires that the maximum brake lever or pedal force is no more than 89 N above and no less than 45 N below the average force determined in the baseline test. Both brakes are applied during the tests. The MOC is obtained by dividing the maximum allowable brake force by the maximum measured force in the fifth recovery stop.

The ECE and JSS fade and recovery tests share common procedures. However, the only similarities between the FMVSS and the ECE/JSS procedures is that a baseline test is followed by ten fade stops. The approach to measuring performance is also different. The FMVSS measures performance based on the required lever or pedal force to maintain a constant deceleration, whereas the ECE/JSS measures performance based on the vehicle deceleration (or equivalent braking distance) given a constant brake lever or pedal force.

Unlike the FMVSS, the ECE and JSS procedures include the use of a fully laden motorcycle and tests the front and rear brakes separately. The fade test speeds are also different, equal to the lesser of 70% of the vehicle's maximum speed or 100 km/h for the front brake and 80 km/h for the rear brake. The ten fade stops require that the engine be connected with the transmission in top gear until the vehicle speed drops to 50% of the initial speed, at which time the engine is disconnected. Finally, the motorcycle pass/fail result is determined with a single stop immediately following the last fade stop, with the engine disconnected.

The ECE and JSS protocols can use either the stopping distance or the MFDD as the criteria to pass the fade and recovery tests. In this case, the performance of the deceleration, or equivalent stopping distance, must not be less than 60% of the baseline test. The MOC for the deceleration output is computed by dividing the measured recovery MFDD by the minimum required MFDD. For the stopping distance MOC, the maximum allowable stopping distance is divided by the measured recovery stopping distance.

The summary results in Table 7 indicates that it was more difficult to pass the ECE and JSS fade and recovery tests than the FMVSS test. The FMVSS average MOC is more than double that of the other tests, and the minimum and maximum values are also higher.

Some of the MOC values listed in Table 7 are below 1.0, indicating that at least one motorcycle failed these respective tests. The severity of the JSS results, although similar to that of the ECE testing, may be exaggerated due to the motorcycle being overloaded. Despite this overloading, the braking results were sometimes better than the properly laden motorcycles in the ECE tests, which reflects well on the respective motorcycle braking systems.

5.5 ECE and JSS ABS Tests

5.5.1 Summary

Only the ECE and JSS standards provide test protocols for motorcycles equipped with ABS, to which the ABS equipped motorcycles were tested, including the Honda VFR800, the Honda ST1100A and the BMW C-1. The BMW results were excluded from the analysis given the absence of replacement tires which can have a significant bearing on the performance results.

The JSS test protocol includes requirements to verify that the ABS does not allow the wheels to lock on low and high-adhesion surfaces, that minimum braking performance is available should the ABS system fail and that the necessary warnings are displayed in such an event. In addition to these basic tests, the ECE regulation includes an “Adhesion Utilization” requirement whereby braking with the ABS system must meet a minimum performance level as compared to braking without the use of ABS. The MOC for the various tests are included in Table 8 and more detailed test data can be found in Appendix C.

Table 8: ABS Margin of Compliance

Test Procedure		Margin of Compliance (MOC)			
		Minimum	Maximum	Standard Deviation	Average
Adhesion Utilization (ECE) - Deceleration		0.79	1.50	0.22	1.17
ABS Failure (ECE)	Stopping Distance	1.10	1.58	0.20	1.32
	Deceleration	1.01	1.38	0.19	1.22
ABS Failure (JSS)	Stopping Distance	1.55	2.57	0.45	1.99
	Deceleration	1.49	2.43	0.42	1.85

5.5.2 Adhesion Utilization

The adhesion utilization test is required by the ECE standard only, and compares the performance of the front and rear ABS brakes separately to the maximum braking performance of the system as a whole, with the ABS disabled. It is evaluated on two road surfaces, a high-adhesion and a low-adhesion surface. The adhesion utilization is defined as the ratio of the tested braking rate (each wheel tested independently) over the maximum braking rate (braking with both wheels), and it must be equal to or greater than 0.70 in order to pass. The MOC is computed by dividing the adhesion utilization result by 0.70.

A summary of the calculated MOC is presented in Table 8 and more detailed test data can be found in Appendix C. Combining the results from both ABS equipped Honda motorcycles, the average MOC for the utilization of adhesion test was 1.17, which is consistent with a stringent requirement. The average result is just above the pass/fail criteria of 1.0, and is also lower than the range of those protocols previously found to be the most stringent (1.24 to 1.34, see shaded cells in Table 7).

The minimum MOC was below 1.0, which indicates that at least one of the vehicles failed the requirement (the Honda VFR in this case). The Honda ST1100 passed on all accounts with an average MOC of 1.3.

The Honda VFR failed the minimum performance requirements while braking with the rear wheel on the high adhesion surface (MOC = 0.79), and showed a margin of compliance of 1.0 for the rear wheel on the low adhesion surface. The limiting factor on the high adhesion surface was the brake pedal pressure which peaked just below the 350 N force limit specified in the ECE standard. It is possible that an adhesion utilization ratio of 0.7 could have been achieved had additional pedal effort been applied. On the low-adhesion surface, whereby the minimum requirement was just met, the rear-wheel ABS would operate before reaching allowable maximum pedal force. The front brakes of the VFR passed the requirement on both the low and high-adhesion surfaces, with an average MOC of 1.2.

5.5.3 Anti-Lock Brake System Failure

This test ensures that the brake system will continue to operate in the event of an ABS malfunction and that a minimum stopping performance is maintained. The ECE and JSS standards share the same test procedures, however, the ECE requires a higher performance level from the motorcycles.

The ECE and JSS protocols can use either stopping distance or deceleration to compare to the pass/fail criteria. The MOC based on the deceleration output is computed by dividing the measured MFDD by the minimum required MFDD. The MOC based on the stopping distance is the maximum allowable stopping distance divided by the measured stopping distance. A summary of the MOC results is presented in Table 8 and more detailed test data are available in Appendix C under the heading "ABS Failure".

The MOC results are higher for the JSS tests as the pass/fail criteria is not as severe. In addition, as indicated earlier, the motorcycles in the JSS tests were loaded beyond the test requirements. Better performance and even higher MOC results could be expected if the vehicles were tested at the required test weight.

Both motorcycles passed the minimum requirements, however, the Honda VFR almost failed the ECE requirement while braking with the rear wheel only, with an MOC of 1.01 based on the deceleration criteria. During that same test, the VFR scored an MOC of 1.10 based on the stopping distance criteria.

With respect to the ECE performance requirements, the average MOC for the stopping distance and MFDD criteria, at 1.32 and 1.22 respectively, is within the same range of those protocols previously found to be the most stringent (1.24 to 1.34, see shaded cells in Table 7). The JSS averages were higher, at 1.99 based on distance and 1.85 based on deceleration, due to lower performance requirements.

5.5.4 Additional Tests

In addition to the above ABS tests, several checks are required by the ECE and the JSS regulations to ensure that the ABS functions properly under certain conditions. One of these checks is assuring that a telltale is illuminated to warn the operator of a power interruption to the electronic ABS controllers, which could lead to a system malfunction.

Both the ECE and the JSS require respective braking tests with the motorcycle's front wheel, rear wheel and both wheels simultaneously while traveling on a high-adhesion road surface and on a low-adhesion road surface. In addition, the ECE requires that the vehicle be braked while traveling from a high-adhesion road surface to a low-adhesion road surface and vice versa. These are not performance tests in which the stopping distance or deceleration is measured. Instead, the pass/fail criteria is based on whether or not wheel lock-up or a tipover occurs during the braking maneuver. Neither of these events took place during testing.

The standards differ further with respect to the initial braking speed, the JSS requiring the lesser of 90% of Vmax or 60 km/h, and the ECE requiring the lesser of 80% of Vmax or 80 km/h. All testing was conducted with the exception of the ECE braking test on a low-adhesion surface, due to time constraints. Given the absence of any wheel lockup in the previous tests, a failure would have been unlikely. The test results can be found in Appendix C.

5.6 ABS Effectiveness Tests

The ABS effectiveness testing was performed to assess the braking performance of ABS equipped motorcycles on various road conditions, with and without the ABS enabled. The proposed test procedure provided by Transport Canada can be found in Appendix E.

5.6.1 Straight Line Stops

The motorcycles were braked to a stop from different speeds, in a straight line path on dry asphalt. The tests were repeated with the ABS enabled and ABS disabled, while both brakes were applied together and simultaneously. The motorcycle stopping distance and MFDD were measured for each test. A summary containing the minimum, maximum, standard deviation and average results are presented inTable 9. Detailed test results can be found in Appendix D.

Table 9: Braking Performance Summary – Straight Line Stops

Motorcycle	Speed (km/h)	ABS Status	Test Criteria	Minimum	Maximum	Standard Deviation	Average
Honda VFR	48.3	On	Stopping Distance (m)	10.84	11.92	0.35	11.39
			MFDD (m/s²)	8.91	9.79	0.41	9.44
		Off	Stopping Distance (m)	11.12	13.90	1.10	12.54
			MFDD (m/s²)	7.60	9.27	0.62	8.36
	128.8	On	Stopping Distance (m)	72.29	76.73	1.80	74.45
			MFDD (m/s²)	8.43	9.53	0.44	9.04
		Off	Stopping Distance (m)	79.60	86.87	2.73	83.64
			MFDD (m/s²)	8.13	9.26	0.48	8.37
Honda ST1100	48.3	On	Stopping Distance (m)	10.74	11.83	0.39	11.30
			MFDD (m/s²)	7.37	10.58	1.21	9.31
		Off	Stopping Distance (m)	10.31	13.25	1.03	11.55
			MFDD (m/s²)	8.39	10.89	0.97	9.62
	128.8	On	Stopping Distance (m)	71.40	80.85	3.20	76.97
			MFDD (m/s²)	8.37	10.36	0.92	9.33
		Off	Stopping Distance (m)	72.37	79.44	2.66	75.24
			MFDD (m/s²)	7.87	9.80	0.72	8.82
BMW C-1	48.3	On	Stopping Distance (m)	12.67	14.16	0.60	13.49
			MFDD (m/s²)	6.55	9.72	1.04	8.22
	60.0	Off	Stopping Distance (m)	24.98	30.37	1.89	28.28
			MFDD (m/s²)	6.26	7.88	0.69	7.11
	73.3	On	Stopping Distance (m)	24.63	30.54	2.49	27.51
			MFDD (m/s²)	8.11	9.73	0.71	8.73
		Off	Stopping Distance (m)	n/a	n/a	n/a	n/a
			MFDD (m/s²)	n/a	n/a	n/a	n/a

The test procedure was to include braking with the ABS operational on the front wheel only, by disabling the rear wheel ABS function. However, none of the motorcycle braking systems could be modified in this way and therefore the test was withdrawn. Straight line braking tests on wet asphalt was also suspended due to inclement weather. These tests will be considered in future undertakings.

The test results are consistent for the Honda VFR, while braking from both test speeds (see Figure 7 and Figure 8). Whether measuring deceleration or stopping distance, better stopping performance was observed with the ABS system enabled, while braking from either speed. An improvement of 9.2 percent or 1.15 meters was recorded while braking from 48.3 km/h, and an improvement of 11 percent or 8.19 meters was recorded while braking from 128.8 km/h. With respect to the MFDD, an average increase in deceleration of 11.4 percent and 7.4 percent was recorded, from speeds of 48.3 and 128.8 km/h respectively, with the ABS enabled.

With respect to the Honda ST1100, there was minimal difference in the average braking performance with or without ABS enabled, from both braking speeds.

The deceleration and braking distance data are contradictory while braking from both speeds. The overall braking distance can be viewed as the prevailing factor in this instance, as it is the overall braking distance which will prevent a collision. With the ABS "on", a shorter average braking distance was recorded from 128.8 km/h, however, a longer average braking distance was recorded from 48.3 km/h.

The BMW C-1 was tested at different speeds, such that only the deceleration data can be discussed. Technical difficulties invalidated some of the test data, represented by "n/a" in Table 9. Despite these difficulties and the fact that this motorcycle was equipped with worn tires, the C-1 deceleration was consistently greater with the ABS "on".

The average results for the Honda VFR, and the limited data for the BMW C-1 were consistent, indicating an overall improvement in braking with the ABS enabled. The results for the Honda ST1100 were not consistent, and the minimum and maximum results for the individual tests covered a wide range in some instances, for all models (see Table 9). The differences in results can be attributed to the motorcycle type (e.g. brake system and tire type), operator control and data acquisition. In summary, the distance and deceleration results indicate that further research and testing is necessary to better isolate and illustrate the effect of ABS for motorcycles.

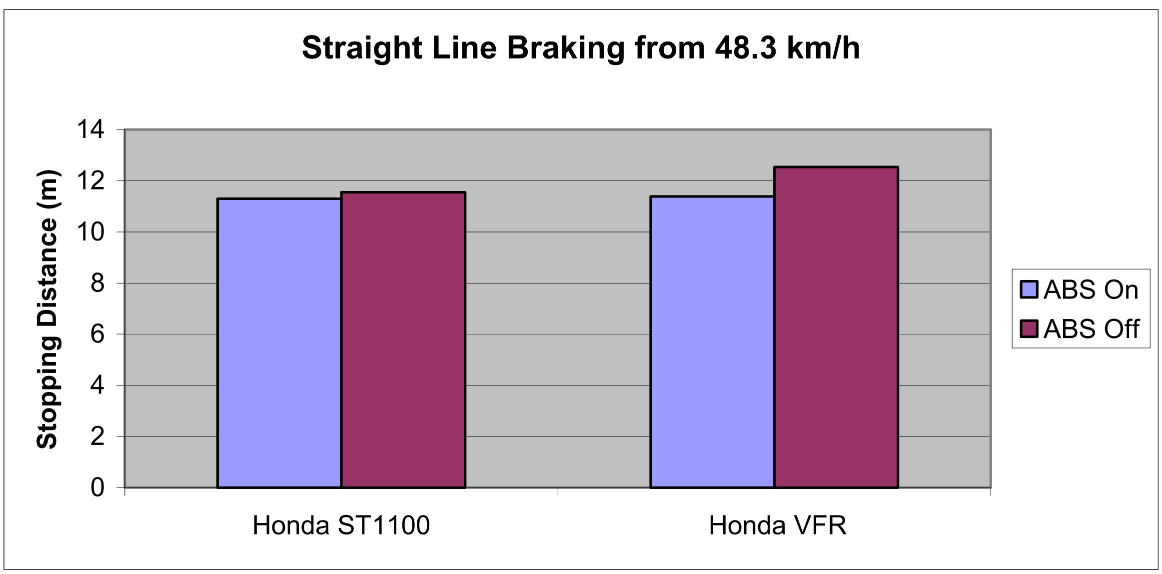

Figure 7: Straight Line Braking from 48.3 km/h – Stopping Distance

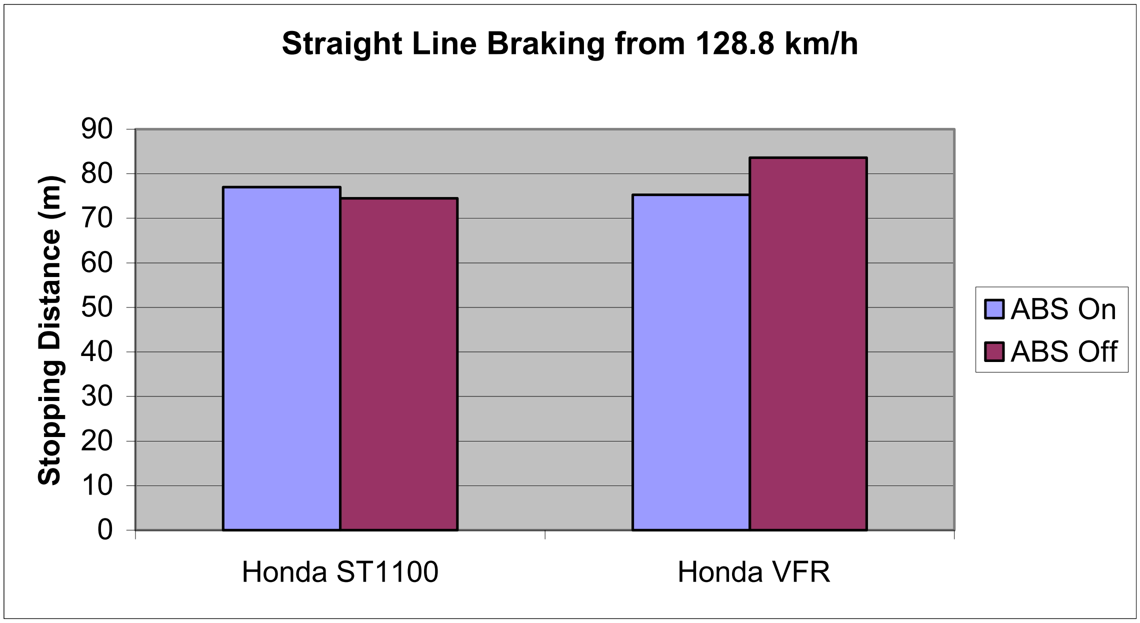

Figure 8: Straight Line Braking from 128.8 km/h – Stopping Distance

5.6.2 Braking in a Turning Maneuver

This test consisted of braking from a speed of 48.3 km/h while following a curved path having a constant radius of 61 m (200 ft), on a dry road surface. The tests were repeated with the ABS enabled and ABS disabled while both brakes were applied together and simultaneously. The motorcycle stopping distance and MFDD were recorded for each test. A summary containing the minimum, maximum, standard deviation and average results are presented in Table 10. Detailed test results can also be found in Appendix D.

Table 10: Braking Performance Summary - Turning Maneuver

Motorcycle	Speed (km/h)	ABS Status	Test Criteria	Minimum	Maximum	Standard Deviation	Average
Honda VFR	48.3	On	Stopping Distance (m)	14.17	19.51	1.87	16.13
			MFDD (m/s²)	7.35	9.18	0.65	8.09
		Off	Stopping Distance (m)	15.15	19.47	1.61	17.04
			MFDD (m/s²)	6.00	8.65	1.00	7.65
Honda ST1100	48.3	On	Stopping Distance (m)	12.38	16.85	1.59	15.43
			MFDD (m/s²)	6.75	8.64	0.80	7.45
		Off	Stopping Distance (m)	n/a	n/a	n/a	n/a
			MFDD (m/s²)	n/a	n/a	n/a	n/a
BMW C-1	60.0	On	Stopping Distance (m)	22.11	25.59	1.27	23.82
			MFDD (m/s²)	6.80	9.99	1.30	8.48
	48.3	Off	Stopping Distance (m)	15.06	16.43	0.63	15.54
			MFDD (m/s²)	6.56	7.91	0.58	7.35

Not enough data were collected to conduct a reasonable analysis for the Honda ST1100, due to corrupt speed signals. The technical difficulty in recording the speed was the result of the optical speed sensor not operating properly as the motorcycle leaned into the turn.

The test results for the Honda VFR are shown in Figure 9, based on distance. Whether measuring deceleration or stopping distance, better stopping performance was observed with the ABS system enabled. A reduction in braking distance of 5.3 percent or 0.91 meters was recorded, as well as an average increase in deceleration of 5.7 percent with the ABS enabled. This improvement is not as significant as compared to braking in a straight line.

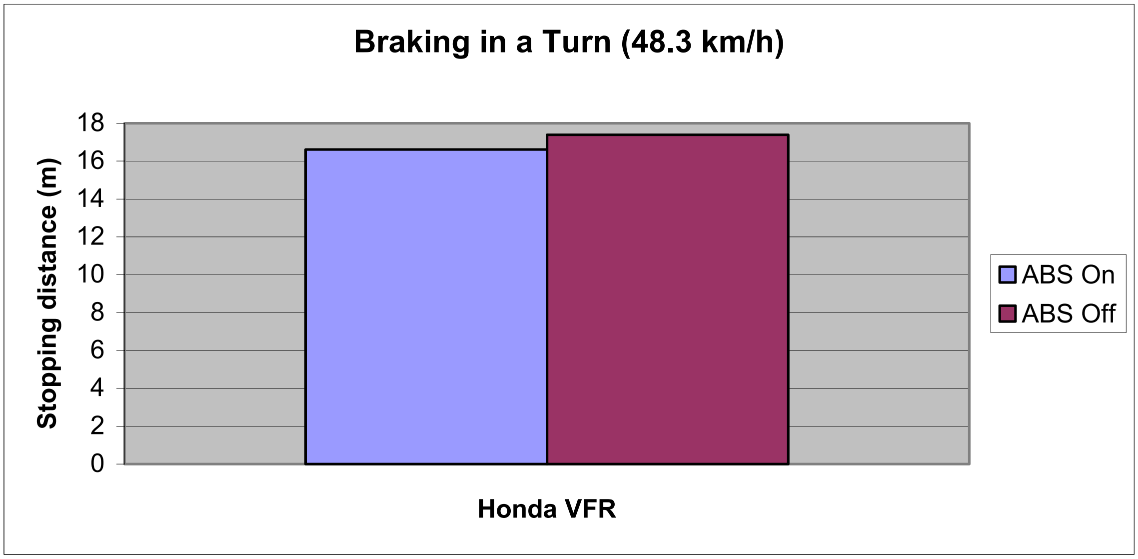

Figure 9: Braking in a Turn – Stopping Distance

The BMW C-1 was tested at different speeds, such that only the deceleration data can be discussed. Despite the fact that this motorcycle was equipped with worn tires, the C-1 deceleration was consistently greater with the ABS “on”. The test results from the turning maneuver for the Honda VFR and the BMW C-1 are consistent with those obtained while braking in a straight line.

6. Conclusion

The motorcycle brake testing procedures were compared for three national motorcycle brake standards; the Federal Motor Vehicle Safety Standard (FMVSS) No. 122, the Economic Commission for Europe (ECE) Regulation No. 78 and the Japan Safety Standard (JSS) J12-61. To examine relative test severity, five motorcycles underwent testing in accordance to these regulations. The results were compared using a method of margin of compliance (MOC).

All three national protocols yielded similar MOC results for the dry test. The FMVSS result was slightly lower, indicating that the associated test methods and performance requirements were the most difficult to achieve of the three protocols.

For the fade and recovery tests, the ECE procedure and performance requirements were the most difficult to achieve. The JSS method for fade and recovery is identical to the ECE and provided very similar results despite the use of an overloaded motorcycle. The FMVSS MOC results were significantly higher, indicating that these procedures and performance requirements were easier to achieve. The observations for the wet brake tests were the same as for the fade and recovery tests, for all three national regulations.

Unlike the ECE and JSS protocols, the FMVSS does not include specific performance requirements for ABS-equipped motorcycles. Compared to the JSS, the ECE regulation includes more stringent ABS specific requirements. Both share the same ABS failure test procedures, however, the ECE regulation requires a higher performance level from the motorcycle brakes and consequently was more difficult to pass.

The results have identified those protocols which were the most difficult to meet, when subjected to a normal compliance evaluation (i.e. the maximum motorcycle performance was not explored). This is not to suggest that these protocol are also the most appropriate to assess braking performance. Significant differences exist between national protocols, such that further investigation into the relevance and effectiveness of each test protocol is needed.

The ABS effectiveness test results suggests that the use of ABS on a motorcycle reduces the stopping distance in a straight-line stopping condition and while traveling through a curve. Additional testing may be useful to determine if the improvement is due solely to equipment performance or if rider confidence is a factor.

7. References

Department of Transportation, National Highway Safety Administration, Federal Motor Vehicle Safety Standards, "Motorcycle Brake Systems", 49 CFR 571 Part 122, Washington, DC., October, 2002.

Economic Commission for Europe, "Uniform Provisions concerning the Approval of Vehicles of Category L with Regard to Brakes", Regulation No. 78, Amendment 3, Geneva, Switzerland, May 1997.

Japanese Safety Standard, "Technical Standard of Two-Wheeled-Vehicle Brake System", J12-61.

Transport Canada, Road Safety and Motor Vehicle Regulation Directorate, "Motorcycle Brake Systems", Technical Standards Document No. 122, Revision 1, Ottawa, Canada, April 20, 2002.

Appendix A : Regulation Comparison Table

Item	Title	FMVSS 122	ECE Regulation 78	Japanese Safety Standard 12-61
1	Scope	Sections S1 - S3: The purpose of this standard is to ensure safe motorcycle braking performance under normal and emergency situations.	1. Applies to the braking of motorcycles with 2 or 3 wheels but does not apply to motorcycles with a design speed not exceeding 25 km/h or fitted for invalid drivers. Vehicle categories: L1: Two wheels, engine < 50 cc, max. speed > 50 km/h L2: Three wheels, engine < 50 cc, max. speed > 50 km/h L3: Two wheels, engine > 50 cc, max. speed > 50 km/h L4: Three wheels - Asymmetric, engine > 50 cc, max. speed > 50 km/h L5: Three wheels - Symmetric, engine > 50 cc, max. speed > 50 km/h	1. Applies to brake systems of two-wheeled motorcycles and two-wheeled motorcycles with sidecars.
2	Definitions	S4: Defined terms are presented.	2. Defined terms are presented.	2. Defined terms are presented.
3	Requirements	S5: Requirements that must be met under conditions (S6) when tested following the procedures (S7). Performance based on stopping distances from specific speeds, measured in feet. If vehicle cannot meet test speed, it is tested at a speed that is a multiple of 5 and is 4 to 8 mph less than the speed attainable in 1 mile. Maximum speed for which stopping distances are provided is 120 mph.	3. Requirement of application for approval including description of vehicle type, diagram of brake components and a vehicle for testing. 4. Approval information including application of approval numbers and marks. Annex 3: Performance based on stopping distance, determined either by measuring the stopping distance or the mean fully developed deceleration (MFDD).	4. Performance based on corrected stopping distance, which is based on measured data, or the mean saturated deceleration (MSD).

Item	Title	FMVSS 122	ECE Regulation 78	Japanese Safety Standard 12-61
4	Type of Service Brake System	S5.1: Each motorcycle shall have a split service brake system OR two independently actuated service brake systems.	2.9.1. Combined Braking System (CBS), for L1 and L3 vehicles, means two brakes on different wheels actuated in combination by a single control. 5.2.1. L1 and L3 vehicles must be equipped with two separate service brake systems with one acting on the front wheel and one acting on the rear wheel. 5.2.3. All L2 vehicles must have sufficient service brakes (one or two) to act on all three wheels and be equipped with a parking brake device. 5.2.4. All L5 vehicles must have a foot controlled brake system that operates on all wheels and a parking brake device.	No such requirement
5	Mechanical Service Brake System	S5.1.1: Failure of any component in a mechanical service brake system shall not result in a loss of braking ability in the other system.	5.2.1.1. The two service brake systems may have a common brake but a failure in one device shall not affect the performance of the other.	No such requirement
6	Hydraulic Service Brake System	S5.1.2 - A leakage failure in a hydraulic service brake system shall not result in a loss of braking ability in the other service brake system. If equipped with a hydraulic system, must have equipment specified in S5.1.2.1 and S5.1.2.2.	5.2.1.1. The two service brake systems may have a common brake but a failure in one device shall not affect the performance of the other.	No such requirement
7	Master Cylinder Reservoirs	S5.1.2.1: Each master cylinder shall have a separate reservoir for each brake circuit, each filler opening shall have its own cover and seal. Each reservoir shall have a minimum capacity to accommodate the displacement of all pistons from new brake components to fully applied worn brake components.	5.2.7.2. Service brake system must possess a reserve of travel to ensure effective braking when brakes become heated and brake linings have reached maximum wear. 5.2.8: For hydraulic service brake systems, fluid reserve receptacles must be such that the level of fluid can be easily checked.	No such requirement
8	Reservoir Labelling	S5.1.2.2: Requirement for brake fluid warning statement. Text, size of lettering, method of application and location are presented.	No such requirement	No such requirement

9	Split Service Brake System	S5.1.3: Additional requirement (S5.1.3.1) for vehicles equipped with split service brake systems.	No such requirement	No such requirement
10	Failure Indicator Lamp	S5.1.3.1: Details of indicator lamp requirements including: Location - in clear view of driver Activation - in event of pressure failure; if fluid level drops to unsafe level Ignition - activated when turned from "off" to "on" position, or to "start" position Duration - activated as long as condition exists Lens - red lens with "Brake Failure" legend	No such requirement	No such requirement
11	Parking Brake	S5.1.4: Applicable only to three-wheeled motorcycles.	5.2.3. All L2 and L5 (three-wheeled) vehicles must be equipped with a parking brake device.	3-4-1-1: Applies to two-wheeled vehicles with sidecars.
12	Visual Inspections	S5.1.5: Installed such that the lining thickness of brake shoes or disk brake friction pads may be visually inspected without removal.	No such requirement	No such requirement
13	Preburnish Effectiveness	S5.2: Preburnish Test S5.2.1: Service brake test includes six stops from 30 mph and six stops from 60 mph, to meet required stopping distances, using both brake systems, with brake temperature between 130-150°F. (S7.3.1) S5.2.2: Partial brake test includes six stops from 30 mph and six stops from 60 mph, to meet required stopping distances, using each brake system individually. (S7.3.2)	No such requirement	No such requirement

14	Burnish Procedure	S7.4: Brakes are burnished using 200 stops from 48.3 km/h to condition surface of new brake components. Between stops, maximum acceleration is used to achieve initial braking speed. The interval before stopping is distance to reduce brake temperature to 130-150°F or 1 mile, whichever occurs first.	No such requirement	No such requirement
15	Dry Stop Tests	S5.3: Second Effectiveness - Following burnish procedure, stops made using both brakes, engine disconnected and vehicle unladen (weight of bike plus 200 lbs.). (S7.5) Requirements: Six stops from 30 mph with stopping distance of 43 ft. (avg. deceleration of 6.9 m/s^2) with brake temperature between 130-150°F. Six stops from 60 mph with stopping distance of 185 ft. (avg. deceleration of 6.4 m/s^2) with brake temperature between 130-150°F. Four stops from 80 mph with stopping distance of 345 ft. (avg. deceleration of 6.1 m/s^2). Four stops from speed that is multiple of 5 mph that is 4 to 8 mph less than speed attainable in 1 mile if greater than 95 mph (max. 120 mph) within distance of 861 ft. (avg. deceleration of 5.4 m/s^2).	Annex 3 - 2.1.1. - 2.2.2. Type O test – one stop required for each brake, vehicle laden and unladen, engine disconnected. For L3 and L4, stop from 60 km/h. For L1 and L2, stops from 40 km/h. Brake temperature less than 100°C (212°F) prior to each stop. Must meet prescribed MFDD, e.g. For laden L3, 4.4 m/s^2 with front brake and 2.9 m/s^2 with rear brake, or equivalent brake distance. For CBS equipped motorcycles, front wheel only, 5.1 m/s^2; rear wheel only, 2.5 m/s^2. If unable to meet due to low adhesion, may be tested laden with both brakes to meet separate requirements, e.g. For L3, 5.8 m/s^2. Annex 3 - 1.4.3. Type O test with engine connected, both brakes together and vehicle unladen for categories L3, L4 and L5. Various tests from 30% of maximum vehicle speed up to the lesser of 80% of that speed or 160 km/h. Maximum practical performance and vehicle behaviour recorded.	3-2-1:Up to six stops with laden vehicle, engine disconnected, from speed at the lower of 90% of vehicle maximum speed or 60 km/h using each brake individually. Brake temperature less than 100°C (212°F) prior to each stop. 4-2-1: Required stopping distance for each condition (e.g. front brake only) dependant on vehicle speed. 4-2-1: Required MSD specified for each condition, e.g. front wheel only, 4.4 m/s^2; rear wheel only, 2.9 m/s^2. For CBS equipped motorcycles, front wheel only, 5.1 m/s^2; rear wheel only, 2.5 m/s^2. 3-2-2: Unladen vehicle tested with both brakes simultaneously and with engine connected. Up to six tests from speed at lower of 80% of vehicle maximum speed or 160 km/h. 4-2-2 Evaluation using stopping distance or MSD of 5.8 m/s^2.

16	Fade and Recovery	S5.4: Fade and Recovery test does not apply to a motorcycle whose speed attainable in 1 mile is 30 mph or less. (S7.6) S5.4.1: Pedal and lever forces used to provide baseline must also meet specified limits of S6.10. Initial brake temperature between 130-150°F. Three stops from 30 mph at 10-11 fps² to compute average peak pedal and lever forces for the three stops. (S7.6.1) S5.4.2: Using both brakes and vehicle unladen, 10 stops from 60 mph at not less than 15 fps². After 10th test, drive 1 mile at 30 mph and then conduct recovery test. (S7.6.2) S5.4.3: Five stops from 30 mph at 10-11 fps². For first four stops, pedal force < 400 N (90 lbs) and hand lever force < 245 N (55 lbs). For fifth stop, peak pedal and lever forces must be within plus 89 N (20 lbs) and minus 45 N (10 lbs) from baseline found in S5.4.1. (S7.6.3), but not less than 0 N (0 lbs).	Annex 3 - 1.6.1.1. For categories L3, L4 and L5, repeated stop tests with laden vehicle. Brakes tested separately unless equipped with CBS. Annex 3 - 1.6.1.2.1. Single dry stop test as described in Annex 3 - 2.1.1. for each brake. Annex 3 - 1.6.1.2.2. With vehicle laden, 10 stops are made and each brake is tested separately. For front brake or CBS, stop from lower of 70% maximum speed or 100 km/h. For rear brake, stop from lower of 70% maximum speed or 80 km/h. Braking interval is 1000m and deceleration is 3 m/s². Braking done with engine connected until speed drops to 50% of initial speed, then engine is disconnected. Initial brake temperature less than 100°C (212°F). Annex 3 - 1.6.1.2.3. Repeat baseline test within one minute of completing fade tests, engine disconnected. Residual performance must not be less than 60% of MFDD achieved in baseline test or equivalent stopping distance. Maximum acceleration allowed by the engine and gearbox to be used between stops.	Same as ECE Reg No. 78
17	Final Effectiveness Test	S5.5: Final Effectiveness test does not apply to a motorcycle whose speed attainable in 1 mile is 30 mph or less. (S7.8) S7.7: Reburnish brakes per S7.4 except make 35 burnish stops instead of 200. S5.5.1:Repeat of Dry Stop tests outlined in S5.3. (S7.8.1)	No such requirement	No such requirement
18	Partial Failure Test	S5.5.2: In the event of a hydraulic leakage failure, the remaining portion of the brake system must operate. Six stops from 30mph and six stops from 60 mph, within specified stopping distances. Repeat for each subsystem. Only applicable to three-wheeled motorcycles. (S7.8.2)	No such requirement	No such requirement

19	Parking Brake System	S5.6: Applicable to 3 wheeled motorcycles. After applying the parking brake and releasing the service brakes, vehicle must remain at rest for 5 minutes for both forward and reverse orientation on a 30% grade. The application of the parking brake must not exceed 400 N (90 lbs.) for a foot operated system and 245 N (55 lbs.) for a hand operated system. (S7.9)	5.1.2.3. Parking brake must hold the vehicle stationary on an up or down gradient and operate on a purely mechanical device. Also, the braking action must be achievable from the driving seat. Annex 3 - 2.3. Vehicle laden on 18% gradient. Annex 3 - 2.4. Applied parking brake force for hand control must be less than 400 N and 500 N for foot control.	Same as ECE Reg No. 78
20	Wet Braking	S5.7 Water Recovery (S7.10) S5.7.1: Pedal and lever forces used to provide baseline must also meet specified limits of S6.10. Three stops from 30 mph at 10-11 fps² to compute average peak pedal and lever forces for the three stops. (S7.10.1) S5.7.2: Completely immerse the rear brake and then the front brake in water for 2 minutes each. Then make five stops from 30 mph at 10-11 fps², using both brakes. For first four stops, pedal force < 400 N (90 lbs) and hand lever force < 245 N (55 lbs). For fifth stop, peak force must be within plus 89 N (20 lbs) and minus 45 N (10 lbs) from baseline found in S5.4.1. (S7.10.2), but not less than 0 lbs.	Annex 3 - 1.4.4. Tests conducted same as dry stop testing, from 60 km/h. Applies to categories L1, L2, L3 and L4. Not required for conventional drum or fully enclosed disc brakes. Annex 3 - 2.5. The decelerations of wet tests is to be compared to that attained in the dry brake test. Brakes tested separately. Annex 3 - 2.5. Equipment required to continuously wet brakes at a flow rate of 15 l/h. The mean deceleration attained 0.5-1.0 seconds after brake application at least 60% of the baseline test. The maximum deceleration must not exceed 120% of the baseline maximum.	Same as ECE Reg No. 78
21	Design Durability	S5.8: Each motorcycle must be capable of completing all braking requirements without damage to the brake system including detachment of brake linings or leakage of brake fluid. Includes disassembly of all brake system components. (S7.11)	5.2.1.1. Components shall be designed such that they are not liable to breakage, are readily accessible for maintenance and exhibit sufficient safety features.	No such requirement
22	Vehicle Weight	S6.1: Unloaded vehicle weight plus 200 lbs. including driver and instrumentation.	Annex 3 - 1.2.1. Mass shall be as prescribed for each type of test. 2.12 Laden mass is maximum mass as specified by manufacturer. 2.13. Unladen mass is vehicle mass plus mass of driver and equipment.	Mass is specified for each type of test. 2-8: Loaded means that up to 65 kg is added to the weight of the vehicle and passenger(s). 2-9: Unloaded means that up to 45 kg has been added to the weight of the vehicle and passenger.
23	Tire Pressure	S6.2: As recommended by manufacturer.	Annex 3: 1.3.1.1. At the start of the test, the tires must be cold and at the pressure recommended by the manufacturer.	3-1-3: As recommended by manufacturer, within 10 kPa.

24	Transmission	S6.3: Unless otherwise specified, all stops are to be made with the engine disconnected.	1.4.2. Most tests performed with the engine disconnected, except for those with automatic transmissions. High speed test (1.4.3.) is conducted with engine connected.	3-2-1-3: The engine shall be disconnected from the drive train. Exception for high-speed braking test (3-2-2-3) when the engine shall be connected.
25	Engine	S6.4: Engine idle speed and ignition timing are set according to manufacturer's recommendations.	No such requirement	No such requirement
26	Ambient Temperature	S6.5: Ambient temperature between 0 and 38 C (32 and 100 F).	No such requirement	No such requirement
27	Wind Velocity	S6.6: Wind velocity is zero.	Annex 3 - 1.3.1.6. Tests performed when no wind exists that may affect results.	3-1-2: Average wind speed is 5 m/s or less.
28	Road Surface	S6.7: Tests to be conducted on a level road surface that meets the following: Skid number: 81 Size: 8 ft wide for two-wheeled motorcycles; vehicle width plus 5 ft for three-wheeled motorcycles Surface: Clean, dry, smooth Portland cement concrete	Annex 3 - 1.3.1.5. Test area to be level, dry and have a surface affording good adhesion.	3-1-1: Unless otherwise specified, the testing shall be conducted on a dry, flat, straight, paved road surface. Need not apply for brake heating procedure (3-2-3-3). 4-1: Lane width of 2.5 m for two-wheeled vehicles; 2.5 m plus tread for two-wheeled vehicles with side-car.
29	Vehicle Position and Wheel Lock	S6.8: Motorcycle is aligned in center of roadway. Stops are to be made without any part of the motorcycle leaving the roadway and without any wheel lockup.	Annex 3 - 1.2.3. Stops are made without wheel lockup, deviation from vehicle course and without abnormal vibration.	3-1-5: No wheel lockup shall occur for tests exceeding 15 km/h. Not applicable to ABS tests. 4-1: Vehicle shall not swerve from lane.
30	Thermo-couples	S6.9: The brake temperature is measured using plug-type thermocouples installed in the center of the most heavily loaded pad or shoe. Typical applications are shown in a figure.	Annex 3 - 1.3.1.3. Brake temperature is measured on the disc or the outside of the drum.	No such requirement
31	Brake Actuation Forces	S6.10: Except when specified, the actuation force must be: Hand Lever: Force > 10 N (2.3 lbs.) and < 245 N (55lbs) where the point of application is 30 mm (1.2") from the end of the grip. Foot Pedal: Force > 25 N (5.6 lbs.) and < 400 N (90 lbs.) where the point of application is in the centre of the foot contact pad.	Annex 3 - 2.4. Hand Lever: For all categories, force < 200 N where the point of application is 50 mm from the end of the lever. Foot Pedal: For L1, L2, L3, L4, force < 350 N. For L5, force < 500 N.	Same as ECE Reg No. 78

32	Anti-Lock Systems	No requirements	Annex 4 - 1.1. Defines minimum performances for ABS fitted to vehicles in categories L1 and L3. Does not specify that ABS is required. Provides various tests to ensure suitable performance and that ABS failure warning telltales are in place. Annex 4 – 5.0. Wheel lock confirmation tests from the lesser of 0.8Vmax or 80 km/h. Braking on high-adhesion and then low-adhesion surfaces, and then while vehicle passes from high-adhesion surface to low-adhesion and vice-versa. Annex 4 – 3.3. ABS failure. Disconnect ABS. Brake each wheel individually, vehicle laden from 60 km/h and decelerate per requirements for normal dry stop. Annex – 4.0. Adhesion utilization. The performance of the respective front and rear brake ABS system must be equal or greater than 70% of the combined braking performance without ABS, on low and high-adhesion surfaces.	Fewer requirements than ECE Reg No. 78. 3-2-5: Wheel lock confirmation tests from the lesser of 0.9Vmax or 60 km/h. Braking on high-adhesion surface and then low-adhesion surfaces only. 3-3: ABS failure similar to ECE, however, need only meet an MSD of 2.9 m/s² or equivalent braking distance. There is no equivalent requirement to the adhesion utilization test in the ECE.

Appendix B : General Test Results

The following tables summarize the detailed test results provided by PMG Technologies.

Dry Test

FMVSS – Dry Test

Motorcycle	Test	State	Engine	Speed (km/h)	Corrected Stopping Distance (m)	Target Stopping Distance (m)	Margin of Compliance
Honda ST1100	1	Unladen	Disconnected	48.3	10.47	13.11	1.25
	2	Unladen	Disconnected	96.6	41.35	56.40	1.36
	3	Unladen	Disconnected	128.8	72.98	105.18	1.44
	4	Unladen	Disconnected	161.0	113.41	182.32	1.61
Harley Davidson	1	Unladen	Disconnected	48.3	12.54	13.11	1.05
	2	Unladen	Disconnected	96.6	46.96	56.40	1.20
	3	Unladen	Disconnected	128.8	81.17	105.18	1.30
	4	Unladen	Disconnected	153.0	122.87	164.63	1.34
Honda VFR	1	Unladen	Disconnected	48.3	10.73	13.11	1.22
	2	Unladen	Disconnected	96.6	40.68	56.40	1.39
	3	Unladen	Disconnected	128.8	75.09	105.18	1.40
	4	Unladen	Disconnected	161.0	120.85	182.32	1.44
Suzuki GZ250	1	Unladen	Disconnected	48.3	10.81	13.11	1.21
	2	Unladen	Disconnected	96.6	40.50	56.40	1.39
	3	Unladen	Disconnected	104.7	57.43	66.16	1.15
BMW C1	1	Unladen	Disconnected	48.3	11.44	13.11	1.15
	2	Unladen	Disconnected	96.6	43.28	56.40	1.30

Notes:

1. This test is conducted in a straight line and under normal dry conditions.
2. The corrected stopping distance is a measured distance, adjusted to account for small variations in the speed at which the stop is initialized.
3. The margin of compliance is computed by dividing the target stopping distance by the corrected stopping distance.
4. All tests were conducted within the requirements of FMVSS 122 and do not necessarily reflect the maximum performance of the motorcycle.

ECE – Dry Test - Stopping Distance

Motorcycle	Test	State	Brake	Engine	Specified Speed (km/h)	Corrected Stopping Distance (m)	Target Stopping Distance (m)	Margin of Compliance
Honda ST1100	1	Laden	Front	Disconnected	60	28.57	33.27	1.16
	2	Laden	Rear	Disconnected	60	28.62	61.38	2.14
	3	Unladen	Front	Disconnected	60	25.93	33.27	1.28
	4	Unladen	Rear	Disconnected	60	32.01	61.38	1.92
	5	Unladen	Both	Connected	59.5	22.79	n/r	n/a
	6	Unladen	Both	Connected	109	64.68	n/r	n/a
	7	Unladen	Both	Connected	158.6	152.3	n/r	n/a
Harley Davidson	1	Laden	Front	Disconnected	60	33.33	37.3	1.12
	2	Laden	Rear	Disconnected	60	38.85	54	1.39
	3	Unladen	Front	Disconnected	60	36.13	n/r	n/a
	4	Unladen	Rear	Disconnected	60	33.56	n/r	n/a
	5	Unladen	Both	Connected	49.7	16.82	n/r	n/a
	6	Unladen	Both	Connected	91.1	51.51	n/r	n/a
	7	Unladen	Both	Connected	132.6	98.51	n/r	n/a
Honda VFR	1	Laden	Front	Disconnected	60	23.22	33.27	1.43
	2	Laden	Rear	Disconnected	60	29.34	61.38	2.09
	3	Unladen	Front	Disconnected	60	20.6	33.27	1.62
	4	Unladen	Rear	Disconnected	60	25.56	61.38	2.40
	5	Unladen	Both	Connected	60	19.27	n/r	n/a
	6	Unladen	Both	Connected	110	59.35	n/r	n/a
	7	Unladen	Both	Connected	160	143.4	n/r	n/a
Suzuki GZ250	1	Laden	Front	Disconnected	60	36.77	37.3	1.01
	2	Laden	Rear	Disconnected	60	44.69	54	1.21
	3	Unladen	Front	Disconnected	60	28.18	n/r	n/a
	4	Unladen	Rear	Disconnected	60	38.65	n/r	n/a
	5	Unladen	Both	Connected	34.3	9.54	n/r	n/a
	6	Unladen	Both	Connected	62.9	27.93	n/r	n/a
	7	Unladen	Both	Connected	91.5	55.62	n/r	n/a
BMW C1	1	Laden	Front	Disconnected	60	30.88	37.3	1.21
	2	Laden	Rear	Disconnected	60	39.82	54	1.36
	3	Unladen	Front	Disconnected	60	25	n/r	n/a
	4	Unladen	Rear	Disconnected	60	37.21	n/r	n/a
	5	Unladen	Both	Connected	29.3	6.49	n/r	n/a
	6	Unladen	Both	Connected	53.7	20.32	n/r	n/a
	7	Unladen	Both	Connected	78.2	44.38	n/r	n/a

ECE – Dry Test - Deceleration

Motorcycle	Test	State	Brake	Engine	Specified Speed (km/h)	Measured MFDD (m/s^2)	Target MFDD (m/s^2)	Margin of Compliance
Honda ST1100	1	Laden	Front	Disconnected	60	5.99	5.1	1.17
	2	Laden	Rear	Disconnected	60	5.12	2.5	2.05
	3	Unladen	Front	Disconnected	60	6.54	5.1	1.28
	4	Unladen	Rear	Disconnected	60	4.6	2.5	1.84
	5	Unladen	Both	Connected	59.5	8.1	n/r	n/a
	6	Unladen	Both	Connected	109	6.81	n/r	n/a
	7	Unladen	Both	Connected	158.6	7.29	n/r	n/a
Harley Davidson	1	Laden	Front	Disconnected	60	5.2	4.4	1.18
	2	Laden	Rear	Disconnected	60	4.43	2.9	1.53
	3	Unladen	Front	Disconnected	60	4.08	n/r	n/a
	4	Unladen	Rear	Disconnected	60	3.82	n/r	n/a
	5	Unladen	Both	Connected	49.7	5.97	n/r	n/a
	6	Unladen	Both	Connected	91.1	6.77	n/r	n/a
	7	Unladen	Both	Connected	132.6	7.28	n/r	n/a
Honda VFR	1	Laden	Front	Disconnected	60	5.69	5.1	1.12
	2	Laden	Rear	Disconnected	60	4.34	2.5	1.74
	3	Unladen	Front	Disconnected	60	7.91	5.1	1.55
	4	Unladen	Rear	Disconnected	60	5.69	2.5	2.28
	5	Unladen	Both	Connected	60	9.45	n/r	n/a
	6	Unladen	Both	Connected	110	8.4	n/r	n/a
	7	Unladen	Both	Connected	160	6.8	n/r	n/a
Suzuki GZ250	1	Laden	Front	Disconnected	60	4.06	4.4	0.92
	2	Laden	Rear	Disconnected	60	5.12	2.9	1.77
	3	Unladen	Front	Disconnected	60	6.79	n/r	n/a
	4	Unladen	Rear	Disconnected	60	4.58	n/r	n/a
	5	Unladen	Both	Connected	34.3	7.35	n/r	n/a
	6	Unladen	Both	Connected	62.9	8.14	n/r	n/a
	7	Unladen	Both	Connected	91.5	7.36	n/r	n/a
BMW C1	1	Laden	Front	Disconnected	60	5.41	4.4	1.23
	2	Laden	Rear	Disconnected	60	3.54	2.9	1.22
	3	Unladen	Front	Disconnected	60	7.33	n/r	n/a
	4	Unladen	Rear	Disconnected	60	3.51	n/r	n/a
	5	Unladen	Both	Connected	29.3	5.97	n/r	n/a
	6	Unladen	Both	Connected	53.7	5.69	n/r	n/a
	7	Unladen	Both	Connected	78.2	6.25	n/r	n/a

Notes:

1. This test is conducted in a straight line and under dry conditions.
2. The corrected stopping distance is a measured distance, adjusted to account for small variations in the speed at which the stop is initialized.
3. The MOC is computed by dividing the target stopping distance by the corrected stopping distance or the measured MFDD by the target MFDD.
4. All tests were conducted within the requirements of ECE No. 78 and do not necessarily reflect the maximum performance of the motorcycle.
5. The acronym "n/r" means no requirement, and " n/a" means not applicable.

JSS – Dry Test - Stopping Distance

Motorcycle	Test	State	Brake	Engine	Speed (km/h)	Corrected Stopping Distance (m)	Target Stopping Distance (m)	Margin of Compliance
Honda ST1100	1	Laden	Front	Disconnected	60	27.54	33.36	1.21
	2	Laden	Rear	Disconnected	60	27.83	61.44	2.21
	3	Unladen	Both	Connected	158.59	133.19	184.30	1.38
Harley Davidson	1	Laden	Front	Disconnected	60	27.61	37.32	1.35
	2	Laden	Rear	Disconnected	60	36.52	53.88	1.48
	3	Unladen	Both	Connected	132.58	86.76	131.00	1.51
Honda VFR	1	Laden	Front	Disconnected	60	25.60	33.36	1.30
	2	Laden	Rear	Disconnected	60	26.53	61.44	2.32
	3	Unladen	Both	Connected	158.59	131.77	184.30	1.40
Suzuki GZ250	1	Laden	Front	Disconnected	60	30.90	37.32	1.21
	2	Laden	Rear	Disconnected	60	42.97	53.88	1.25
	3	Unladen	Both	Connected	91.52	44.62	65.27	1.46
BMW C1	1	Laden	Front	Disconnected	60	20.47	37.32	1.82
	2	Laden	Rear	Disconnected	60	36.16	53.88	1.49
	3	Unladen	Both	Connected	78.16	33.78	48.75	1.44

JSS – Dry test - Deceleration

Motorcycle	Test	State	Brake	Engine	Target Speed (km/h)	Measured MFDD (m/s^2)	Target MFDD (m/s^2)	Margin of Compliance
Honda ST1100	1	Laden	Front	Disconnected	60	6.52	5.1	1.28
	2	Laden	Rear	Disconnected	60	5.12	2.5	2.05
	3	Unladen	Both	Connected	158.59	7.09	5.8	1.22
Harley Davidson	1	Laden	Front	Disconnected	60	5.72	4.4	1.30
	2	Laden	Rear	Disconnected	60	5.14	2.9	1.77
	3	Unladen	Both	Connected	132.58	8.70	5.8	1.50
Honda VFR	1	Laden	Front	Disconnected	60	5.73	5.1	1.12
	2	Laden	Rear	Disconnected	60	5.18	2.5	2.07
	3	Unladen	Both	Connected	158.59	8.71	5.8	1.50
Suzuki GZ250	1	Laden	Front	Disconnected	60	5.18	4.4	1.18
	2	Laden	Rear	Disconnected	60	3.52	2.9	1.21
	3	Unladen	Both	Connected	91.52	8.42	5.8	1.45
BMW C1	1	Laden	Front	Disconnected	60	7.35	4.4	1.67
	2	Laden	Rear	Disconnected	60	4.87	2.9	1.68
	3	Unladen	Both	Connected	78.16	9.18	5.8	1.58

Notes:

1. This test is conducted in a straight line and under dry conditions.
2. The corrected stopping distance is a measured distance, adjusted to account for small variations in the speed at which the stop is initialized.

3. The MOC is computed by dividing the target stopping distance by the corrected stopping distance or the measured MFDD by the target MFDD.
4. All tests were conducted within the requirements of JSS 12-61 and do not necessarily reflect the maximum performance of the motorcycle.

Wet Brake Tests

FMVSS – Water Recovery Test

Motorcycle	Brake	Baseline Average Force (N)	Minimum Allowable (N)	Maximum Allowable (N)	Recovery Stop (N)	Margin of Compliance
Honda ST1100	Front	32.6	0	121.6	37.1	3.3
	Rear	124.8	80.8	213.8	95.2	2.2
Harley Davidson	Front	23.8	0	112.8	26.9	4.2
	Rear	83.3	39.3	172.3	96.7	1.8
Honda VFR	Front	24.1	0	113.1	23.4	4.8
	Rear	103.4	59.4	192.4	135.3	1.4
Suzuki GZ250	Front	36.8	0	125.8	49.8	2.5
	Rear	85.6	41.6	174.6	98.6	1.8
BMW C1	Front	50.1	6.1	139.1	42	3.3
	Rear	60.2	16.2	149.2	51.8	2.9

Notes:

1. Three stops under dry conditions are conducted to determine the baseline average force, from 48.3 km/h. The brake systems are then immersed in water. Five water recovery tests are conducted and the results of the fifth test are used to assess performance. Front and rear brakes are tested together.
2. The maximum and minimum allowable values are based on the baseline average.
3. The MOC is computed by dividing the maximum allowable brake force by the maximum measured recovery stop brake force.
4. All tests were conducted within the requirements of FMVSS 122 and do not necessarily reflect the maximum performance of the motorcycle.

ECE/JSS –Wet Brake Test

			0.5-1.0 Average Deceleration (m/s^2)				Maximum Deceleration (m/s^2)			
	Motorcycle	Brake	Average Baseline	60%	Average Wet	Margin of Compliance	Maximum Baseline	120%	Maximum Wet	Margin of Compliance
ECE	Honda ST1100	Front	3.26	1.96	2.49	1.27	3.8	4.56	4.07	1.12
		Rear	2.58	1.55	3.71	2.40	4.34	5.21	4.61	1.13
	Harley Davidson	Front	1.94	1.16	2.44	2.10	4.34	5.21	4.07	1.28
		Rear	3.07	1.84	2.85	1.55	4.61	5.53	4.88	1.13
	Honda VFR	Front	3.35	2.01	3.30	1.64	4.61	5.53	4.34	1.27
		Rear	3.57	2.14	3.21	1.50	4.88	5.86	3.8	1.54
	Suzuki GZ250	Front	2.49	1.49	2.58	1.73	4.34	5.21	4.34	1.20
		Rear	Not required for drum brake, as per protocol.							
	BMW C1	Front	1.81	1.09	1.99	1.83	4.88	5.86	5.15	1.14
		Rear	2.53	1.52	2.35	1.55	4.61	5.53	5.15	1.07
JSS	Honda ST1100	Front	2.35	1.41	1.99	1.41	4.07	4.88	4.34	1.13
		Rear	2.94	1.76	2.58	1.46	4.07	4.88	3.53	1.38
	Harley Davidson	Front	2.53	1.52	2.17	1.43	3.8	4.56	3.26	1.40
		Rear	2.35	1.41	1.85	1.31	5.15	6.18	3.26	1.90
	Honda VFR	Front	2.67	1.60	2.58	1.61	4.34	5.21	4.07	1.28
		Rear	2.67	1.60	3.16	1.97	4.61	5.53	4.07	1.36
	Suzuki GZ250	Front	3.35	2.01	2.76	1.37	5.97	7.16	4.88	1.47
		Rear	Not required for drum brake, as per protocol.							
	BMW C1	Front	2.22	1.33	2.26	1.70	4.88	5.86	4.34	1.35
		Rear	3.07	1.84	3.07	1.67	4.61	5.53	5.43	1.02

Notes:

1. One stop under dry conditions is conducted to determine the baseline performance for comparison. The disc brake systems are continuously sprayed with water during the wet test. Tests are conducted from 60 km/h. A single stop following the baseline test is used to determine the pass or fail. Brakes are tested separately.
2. The "0.5-1.0 Average Deceleration" cell is the average deceleration measured between 0.5 and 1.0 seconds after application of the brake.
3. Based on average deceleration, the MOC is computed by dividing the average wet deceleration by 60% of the average baseline deceleration. Based on maximum deceleration, the MOC is computed by dividing 120% of the maximum baseline deceleration by the maximum wet deceleration.
4. All tests were conducted within the requirements of ECE No. 78 and JSS 12-61 and do not necessarily reflect the maximum performance of the motorcycle.

Fade and Recovery Tests

FMVSS – Fade and Recovery Test

Motorcycle	Brake	Baseline Average (N)	Minimum (N)	Maximum (N)	Recovery Stop (N)	Margin of Compliance
Honda ST1100	Front	32.1	0	121.1	30.8	3.9
	Rear	102.7	58.7	191.7	114.7	1.7
Harley Davidson	Front	35.3	0	124.3	40.5	3.1
	Rear	90.7	46.7	179.7	94.7	1.9
Honda VFR	Front	24.6	0	113.6	24.4	4.7
	Rear	135.9	91.9	224.9	92.8	2.4
Suzuki GZ250	Front	37.1	0	126.1	28.3	4.5
	Rear	110.4	66.4	199.4	85	2.3
BMW C1	Front	28.3	0	117.3	26.4	4.4
	Rear	39.4	0	128.4	63.5	2.0

Notes:

1. Three stops are conducted to determine the baseline average force, from 48.3 km/h. The fade tests are conducted at 96.6 km/h and consist of 10 stops.
2. Five recovery stops are made from 48.3km/h and the brake force results from the fifth recovery stop determine the pass or fail. The brake force must fall within a range that is 89 N above and 45 N below the average force determined in the baseline tests. Front and rear brakes are tested together.
3. The MOC is computed by dividing the maximum allowable brake force by the maximum brake force in the recovery stop.
4. All tests were conducted within the requirements of FMVSS 122 and do not necessarily reflect the maximum performance of the motorcycle.

ECE/JSS – Fade and Recovery Test

			Stopping Distance (m)				Measured MFDD (m/s^2)			
	Motorcycle	Brake	Baseline	Target	Recovery Stop	Margin of Compliance	Baseline	60%	Recovery Stop	Margin of Compliance
ECE	Honda ST1100	Front	28.57	43.62	36.78	1.19	5.99	3.59	4.33	1.20
		Rear	28.62	43.70	42.29	1.03	5.12	3.07	3.81	1.24
	Harley Davidson	Front	33.33	51.56	45.80	1.13	5.20	3.12	2.99	0.96
		Rear	38.85	60.76	40.34	1.51	3.34	2.00	4.06	2.03
	Honda VFR	Front	23.22	34.71	27.05	1.28	5.69	3.41	5.46	1.60
		Rear	29.34	44.90	28.09	1.60	4.34	2.60	4.60	1.77
	Suzuki GZ250	Front	36.77	57.28	40.56	1.41	4.06	2.44	3.78	1.55
		Rear	44.69	70.48	44.55	1.58	5.12	3.07	3.79	1.23
	BMW C1	Front	30.88	47.47	38.97	1.22	5.41	3.25	3.79	1.17
		Rear	39.86	62.37	35.05	1.78	3.54	2.12	4.33	2.04
JSS	Honda ST1100	Front	27.56	41.94	36.76	1.14	6.52	3.91	3.80	0.97
		Rear	31.40	43.70	35.76	1.22	4.05	2.43	4.09	1.68
	Harley Davidson	Front	35.76	51.56	40.72	1.27	4.35	2.61	3.28	1.26
		Rear	36.52	60.76	62.91	0.97	3.83	2.30	2.47	1.07
	Honda VFR	Front	26.14	39.56	19.42	2.04	5.38	3.23	n/a	n/a
		Rear	32.82	50.69	41.53	1.22	4.34	2.60	2.99	1.15
	Suzuki GZ250	Front	35.89	55.82	40.11	1.39	4.04	2.42	4.09	1.69
		Rear	42.97	67.61	51.94	1.30	2.11	1.27	2.72	2.15
	BMW C1	Front	29.01	44.36	33.04	1.34	4.58	2.75	4.59	1.67
		Rear	40.08	62.80	40.84	1.54	3.27	1.96	3.25	1.66

Notes:

1. The baseline brake force is measured from a single stop followed by 10 fade stops. All tests are conducted from the lower of 70 % of the vehicle's maximum speed or 100 km/h for the front brake (or 80 km/h for the rear brake). A single stop following the fade tests is used to determine the pass or fail. Brakes are tested separately.
2. During the fade stops, the engine is to remain connected until the vehicle speed drops to 50% of the initial speed, at which time the engine is disconnected. The highest gear is used during the initial stage of braking. The engine is disconnected in the final evaluation stop.
3. The margin of compliance is computed by dividing the target stopping distance by the measured recovery stopping distance or by dividing the measured MFDD by 60% of the baseline MFDD. For information on the determination of the target stopping distance, please refer to ECE No. 78.
4. The data that are listed as not available (i.e. n/a) was rejected due to a testing error, e.g. failure of the optical speed sensor.
5. All tests were conducted within the requirements of ECE No. 78 and JSS 12-61 and do not necessarily reflect the maximum performance of the motorcycle.

Appendix C : ECE/JSS ABS Test Results

Adhesion Utilization – ECE

	Test #	Brake	Coefficient of Adhesion	Tested Ratio α (Zmax/Zm)	Target Ratio α (Zmax/Zm)	Margin of Compliance
Honda ST1100	1	Front	High	0.79	0.7	1.13
	2	Rear	High	0.86	0.7	1.23
	3	Front	Low	1.05	0.7	1.50
	4	Rear	Low	0.93	0.7	1.33
Honda VFR	1	Front	High	0.77	0.7	1.10
	2	Rear	High	0.55	0.7	0.79
	3	Front	Low	0.92	0.7	1.31
	4	Rear	Low	0.7	0.7	1.00
BMW C1	1	Front	High	0.74	0.7	1.06
	2	Rear	High	0.4	0.7	0.57
	3	Front	Low	0.61	0.7	0.87
	4	Rear	Low	0.74	0.7	1.06

Notes:

1. All tests were performed with the vehicles in the unladen state and with an initial speed of 60 km/h.
2. The margin of compliance is computed by dividing the tested utilization ratio by the target utilization ratio. For information on the determination of the utilization ratio, please refer to ECE No. 78.
3. All tests were conducted within the requirements of ECE No. 78 and do not necessarily reflect the maximum performance of the motorcycle.

ABS Failure – ECE

	Test	Brake	Corrected Stopping Distance (m)	Target Stopping Distance (m)	Margin of Compliance	Measured MFDD (m/s^2)	Target MFDD (m/s^2)	Margin of Compliance
Honda ST1100	1	Front	24.46	33.27	1.36	7.04	5.1	1.38
	2	Rear	27.08	33.27	1.23	5.69	5.1	1.12
Honda VFR	1	Front	21.01	33.27	1.58	7.01	5.1	1.37
	2	Rear	30.11	33.27	1.10	5.17	5.1	1.01
BMW C1	1	Front	24.40	37.30	1.53	6.81	4.4	1.55
	2	Rear	38.69	54.00	1.40	5.37	2.9	1.85

ABS Failure – JSS

	Test	Brake	Corrected Stopping Distance (m)	Target Stopping Distance (m)	Margin of Compliance	Measured MFDD (m/s^2)	Target MFDD (m/s^2)	Margin of Compliance
Honda ST1100	1	Front	31.23	53.88	1.73	4.64	2.9	1.60
	2	Rear	34.78	53.88	1.55	4.32	2.9	1.49
Honda VFR	1	Front	20.98	53.88	2.57	7.05	2.9	2.43
	2	Rear	25.83	53.88	2.09	5.46	2.9	1.88
BMW C1	1	Front	n/a	53.88	n/a	n/a	2.9	n/a
	2	Rear	n/a	53.88	n/a	n/a	2.9	n/a

Notes:

1. The following tests were performed with the vehicles in the laden state and with an initial speed of 60 km/h.
2. To simulate a failure of the ABS, the ABS was disconnected in all tests.
3. The corrected stopping distance is a measured distance, adjusted to account for small variations in the speed at which the stop is initialized.
4. The margin of compliance is computed by dividing the target stopping distance by the corrected stopping distance or by dividing the measured MFDD by the target MFDD.
5. All tests were conducted to the procedures of ECE No. 78 and JSS 12-61 and do not necessarily reflect the maximum performance of the motorcycle.
6. The data listed as "n/a" indicates that data is not available.

Additional Tests – Wheel Lock-up Confirmation Test - ECE

Motorcycle	Test	Type	Brake Applied	Wheel Lock-up
Honda ST1100	1	Full Force Suddenly Applied – High Adhesion	Front	No
	2		Rear	No
	3		Both	No
	4	High to Low Adhesion	Front	No
	5		Rear	No
	6		Both	No
	7	Low to High Adhesion	Front	No
	8		Rear	No
	9		Both	No
Honda VFR	1	Full Force Suddenly Applied – High Adhesion	Front	No
	2		Rear	No
	3		Both	No
	4	High to Low Adhesion	Front	No
	5		Rear	No
	6		Both	No
	7	Low to High Adhesion	Front	No
	8		Rear	No
	9		Both	No
BMW C1	1	Full Force Suddenly Applied – High Adhesion	Front	No
	2		Rear	No
	3		Both	No
	4	High to Low Adhesion	Front	No
	5		Rear	No
	6		Both	No
	7	Low to High Adhesion	Front	No
	8		Rear	No
	9		Both	No

Notes:

1. The purpose of this test was to indicate whether or not wheel lock-up occurred and no other measurements were recorded.
2. All tests were performed with the vehicles in the unladen state and at an initial braking speed of the lesser 0.8 Vmax or 80 km/h.
3. All tests were conducted within the requirements of ECE No. 78.

Additional Tests – Wheel Lock-up Confirmation Test - JSS

Motorcycle	Test	Type	Brake Applied	Wheel Lock-up
Honda ST1100	1	High Adhesion	Both	No
	2	Low Adhesion	Both	No
Honda VFR	1	High Adhesion	Both	No
	2	Low Adhesion	Both	No
BMW C1	1	High Adhesion	Both	No
	2	Low Adhesion	Both	No

Notes:

1. The purpose of this test was to indicate whether or not wheel lock-up occurred and no other measurements were recorded.
2. All tests were performed with the vehicles in the unladen state and at an initial braking speed of the lesser of 0.9 Vmax or 60 km/h.
3. All tests were conducted within the requirements of JSS 12-61.

Appendix D : ABS Effectiveness Test Results

Straight Line Braking Evaluation

Motorcycle	Test	ABS Status	Specified Speed (km/h)	Corrected Stopping Distance (m)	Measured MFDD (m/s^2)
Honda ST1100	1	On	48.3	11.67	10.29
	2	On	48.3	11.23	9.46
	3	On	48.3	10.74	9.74
	4	On	48.3	11.17	8.42
	5	On	48.3	11.18	10.53
	6	On	48.3	11.83	7.37
	7	On	128.8	76.42	8.4
	8	On	128.8	78.61	8.73
	9	On	128.8	76.29	10.03
	10	On	128.8	80.85	8.37
	11	On	128.8	78.26	10.36
	12	On	128.8	71.40	10.09
	1	Off	48.3	11.79	9.51
	2	Off	48.3	10.31	10.27
	3	Off	48.3	13.25	8.39
	4	Off	48.3	11.37	8.63
	5	Off	48.3	10.70	10.89
	6	Off	48.3	11.85	10.05
	7	Off	128.8	79.44	9.42
	8	Off	128.8	76.70	9.01
	9	Off	128.8	72.37	8.39
	10	Off	128.8	73.13	7.87
	11	Off	128.8	73.74	8.45
	12	Off	128.8	76.08	9.80
Honda VFR	1	On	48.3	11.36	8.94
	2	On	48.3	11.50	9.48
	3	On	48.3	10.84	9.73
	4	On	48.3	11.36	9.72
	5	On	48.3	11.34	9.80
	6	On	48.3	11.92	8.91
	7	On	128.8	75.84	9.53
	8	On	128.8	76.73	8.43
	9	On	128.8	75.01	8.64
	10	On	128.8	72.29	8.97
	11	On	128.8	74.38	9.19
	12	On	128.8	72.45	9.47
	1	Off	48.3	13.07	8.17
	2	Off	48.3	11.46	9.18
	3	Off	48.3	13.38	7.58
	4	Off	48.3	13.90	8.14
	5	Off	48.3	12.29	8.13
	6	Off	48.3	11.12	8.93
	7	Off	128.8	86.87	8.39

	8	Off	128.8	83.87	7.84
	9	Off	128.8	79.60	9.26
	10	Off	128.8	81.38	8.41
	11	Off	128.8	85.84	8.17
	12	Off	128.8	84.28	8.13
BMW C1	1	On	48.3	14.16	7.85
	2	On	48.3	13.68	8.11
	3	On	48.3	13.81	9.72
	4	On	48.3	13.80	8.70
	5	On	48.3	12.67	6.55
	6	On	48.3	12.84	8.41
	7	On	73.3	30.54	8.44
	8	On	73.3	28.71	8.15
	9	On	73.3	24.63	8.45
	10	On	73.3	25.83	9.51
	11	On	73.3	25.53	9.73
	12	On	73.3	29.81	8.11
	1	Off	60.0	28.34	6.26
	2	Off	60.0	30.37	6.5
	3	Off	60.0	28.34	7. 35
	4	Off	60.0	29.84	7.84
	5	Off	60.0	27.80	6.8
	6	Off	60.0	24.98	7.88
	7	Off	73.3	n/a	n/a
	8	Off	73.3	n/a	n/a
	9	Off	73.3	n/a	n/a
	10	Off	73.3	n/a	n/a
	11	Off	73.3	n/a	n/a
	12	Off	73.3	n/a	n/a

Notes:

1. All tests were performed with the vehicle in the unladen state and with both brakes applied simultaneously. For more information regarding the test procedure, please see Appendix E.
2. The data that are listed as not available (i.e. n/a) was rejected due to a testing error, e.g. failure of the optical speed sensor.
3. The corrected stopping distance is a measured distance, adjusted to account for small variations in the speed at which the stop is initialized.

Turning Maneuver Braking Evaluation

Motorcycle	Test	ABS Status	Specified Speed (km/h)	Corrected Stopping Distance (m)	Measured MFDD (m/s^2)
Honda ST1100	1	On	48.3	15.60	6.76
	2	On	48.3	12.38	8.64
	3	On	48.3	15.65	6.78
	4	On	48.3	15.58	7.88
	5	On	48.3	16.85	7.91
	6	On	48.3	16.53	6.75
	1	Off	48.3	n/a	n/a
	2	Off	48.3	n/a	n/a
	3	Off	48.3	n/a	n/a
	4	Off	48.3	n/a	n/a
	5	Off	48.3	n/a	n/a
	6	Off	48.3	n/a	n/a
Honda VFR	1	On	48.3	19.51	7.89
	2	On	48.3	15.36	7.59
	3	On	48.3	15.44	8.17
	4	On	48.3	14.17	9.18
	5	On	48.3	16.89	7.32
	6	On	48.3	15.41	8.37
	1	Off	48.3	19.47	8.64
	2	Off	48.3	15.51	8.71
	3	Off	48.3	18.05	6.00
	4	Off	48.3	16.73	7.33
	5	Off	48.3	15.15	7.89
	6	Off	48.3	17.32	7.35
BMW C1	1	On	60.0	24.96	7.55
	2	On	60.0	23.07	9.99
	3	On	60.0	25.59	8.44
	4	On	60.0	23.64	8.09
	5	On	60.0	23.52	9.99
	6	On	60.0	22.11	6.80
	1	Off	48.3	15.57	7.59
	2	Off	48.3	16.43	7.34
	3	Off	48.3	15.11	6.56
	4	Off	48.3	15.06	7.91
	5	Off	48.3	n/a	n/a
	6	Off	48.3	n/a	n/a

Notes:

1. All tests were performed with the vehicle in the unladen state and with both brakes applied simultaneously. See Appendix E for more details.
2. The data that are listed as not available (i.e. n/a) was rejected due to a testing error, e.g. failure of the optical speed sensor.
3. The corrected stopping distance is a measured distance, adjusted to account for small variations in the speed at which the stop is initialized.

Appendix E : ABS/CBS Test Procedure

Motorcycles equipped with ABS or CBS – Proposed Testing Procedures[i]

These tests will be carried out on three motorcycles: the Honda VFR, the Honda ST1100A and the BMW C-1 Executive. Both Hondas are equipped with CBS, whereas the BMW is equipped with ABS only.

Pre-test Preparations

The vehicle tire pressures will be set to the manufacturers' requirements. Braking will take place with the engine disconnected, thus eliminating engine braking from the variables.

The vehicles will be equipped with new tires and brake friction components (rotors/pads, drums/shoes). The brakes must then be burnished by making 200 brake stops from 48.3 kph (30 mph), with both brakes applied, at a deceleration rate of 3.66 m/s^2 (12 ft/sec^2). The braking interval shall be 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 occurs first. Accelerate at maximum rate to 48.3 km/h (30 mph) immediately after each stop and maintain that speed until making the next stop. After burnishing, adjust the brakes in accordance with the manufacturer's recommendation.

Testing

The purpose is to assess the braking performance of ABS or CBS equipped motorcycles.

A. This evaluation will be accomplished by running a full series of tests with ABS fully enabled, and then running the same tests with the ABS system partially and then completely disabled. Tire flat spots may occur as the ABS is disabled, therefore these tests should be saved for last. In summary, the full series of tests will be run under each of the following brake system conditions:

   1. With ABS fully operational
   2. With front-wheel only ABS operational (i.e. rear-wheel ABS disabled)
   3. With the complete ABS disabled

B. Braking performance will be evaluated with the following series of tests:

   1. Braking in a straight line on dry asphalt, from a speed of 48.3 kph (30 mph) and from 75 % of the vehicle's top speed or 128.8 kph (80 mph), whichever is lower.

2. Braking in a straight line on wet asphalt, from a speed of 48.3 kph (30 mph).
3. Braking while in a turning maneuver, on dry asphalt, from a speed of 48.3 kph (30 mph). Braking will occur while maintaining a turning curvature following a 200 foot (61 meter) radius path.

Initial brake temperature will be between 54.4° C (130° F) and 65.6° C (150° F) prior to each maneuver. Each brake system condition in (A) will be tested 6 times to each scenario in (B), for a total of 18 braking tests per brake system condition (ABS enabled/partially disabled/fully disabled), and 54 braking tests per motorcycle. In order to assess maximum braking performance (i.e. minimum braking distance), both front and rear wheel brake controls will be operated in each maneuver.

For the motorcycles equipped with CBS (i.e. the Hondas), the performance of the LBS technology will become evident as the ABS is disabled. In this instance, LBS performance should be the same as independent wheel braking systems (i.e. motorcycles without LBS), as both front and rear wheel brake controls will be operated to obtain maximum braking performance.

For the motorcycle equipped with ABS only (BMW C-1), the performance of standard independent wheel braking will become evident as the ABS is disabled.

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[i] Revised September 25/02