A Comparison of Stopping Distance Performance for Motorcycles Equipped with ABS, CBS and Conventional Hydraulic Brake Systems

Donovan Green
United States Department of Transportation, National Highway Traffic Safety Administration

International Motorcycle Safety Conference
Long Beach, California
March 28 – March 30, 2006

ABSTRACT

In 2003, the U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA) in cooperation with Transport Canada (TC) conducted a motorcycle brake research project. The objective of this testing program was to assess the effectiveness of anti-lock braking systems (ABS) and combined brake systems (CBS) on motorcycles using various braking maneuvers and loading conditions. The results indicate that ABS generally improved stopping distance performance under most test conditions, and CBS improved braking performance when only the rear (foot) pedal was applied.

INTRODUCTION

This paper discusses and compares the braking performance of motorcycles with ABS and CBS with the braking performance of motorcycles with conventional hydraulic brake systems.

Motorcycle brake regulations have not kept pace with the advancement of modern technologies. With the improvement of disc brake systems and by incorporating ABS and CBS, modern motorcycles can be equipped with sophisticated and effective braking systems. In addition, the motorcycle manufacturing industry has become a global industry, serving a global market.

Certain innovations in motorcycle braking may provide increased margins of safety for their riders when compared with a similar motorcycle without the supplementary technology.

In a joint research program between NHTSA and TC, several motorcycles were tested to evaluate the capabilities of their braking technology.

A total of six motorcycles were tested under several different test conditions and maneuvers. The braking test maneuvers included: braking in a straight line on a dry surface, braking in a straight line on a wet surface, and braking while in a turn on a dry surface. {Note: This paper will focus primarily on the straight-line brake test results.} The motorcycle test conditions included: fully-loaded and lightly-loaded vehicle weights, ABS on/off and CBS on/off. For additional information on braking in a turn results, please visit http://dms.dot.gov/ docket No. 11950.

TESTS

Testing was performed with six motorcycles, representing the dual-purpose, sport, and sport touring segments for motorcycles. The following motorcycles were used in the tests:

1. 2002 Honda VFR 800 with ABS & CBS
2. 2002 BMW F650 with ABS
3. 2002 BMW R 1150R with ABS & CBS
4. 2002 BMW R 1150R without ABS or CBS
5. 2004 Yamaha FJR1300 with ABS
6. 2004 Yamaha FJR1300 without ABS

Motorcycle Description

The motorcycles were selected to represent a cross-section of motorcycle types while providing a sufficient number of motorcycles equipped with ABS. Some were also equipped with CBS, where the application of at least one of the brake controls actuates the front and rear brakes.

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

The BMW R1150R and Yamaha FJR 1300 are also available with optional ABS. However, the ABS on these motorcycles either cannot be disabled or the braking components are different from the non-ABS model, requiring one of each model for comparison testing.

Test Conditions

Motorcycle brake performance tests were conducted on an asphalt road surface having a uniform skid number. The skid number was measured with ASTM procedure ASTM E274 at regular intervals to assure consistency in the results (see Table 1.). For wet surface testing, the test track was wetted with a water truck, and the wetting procedure was repeated every three stops.

Table 1: Skid Numbers

Test Maneuver	Skid Number
Dry surface braking	87 (dry asphalt)
Wet surface braking	48 (wet asphalt)

The vehicles were equipped with new tires and brake friction components (rotors and pads). The vehicle tire pressures were set to the manufacturer's recommendations. No additional tire or brake friction component changes were made for the duration of the tests. The brake temperature prior to braking was between 0 and 100 degrees Celsius.

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

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

Burnishing

The brakes were then burnished to the requirements of the United States Federal Motor Vehicle Safety Standard (FMVSS) No. 122. The burnishing procedure subjects the braking system to 200 brake stops from 48 km/h (30 mph), with both brakes applied, at a deceleration rate of 3.7 m/s^2 (12 ft/s^2). The braking interval was either the distance necessary to reduce the initial brake temperature to between 54°C (130°F) and 66°C (150°F) or 1.6 km (1 mile), whichever occurred first. The motorcycle was accelerated at maximum rate to 48.3 km/h (30 mph) immediately after each stop, and that speed was maintained until initiating the next stop. During braking, the engine was disconnected from the drive-train. After burnishing, the brakes were adjusted in accordance with the manufacturer's recommendation.

Test Procedure

The motorcycle brake tests were performed by braking both the front wheel and rear wheel simultaneously.

Each motorcycle was tested in a lightly loaded condition, with the brake temperature before braking at 100°C or lower. The motorcycle was tested from an initial speed of 80% of the model's maximum velocity, or VMAX (a value up to 160 km/h, acquired by multiplying VMAX by 0.8) ± 5 km/h.

When the hand-operated brake lever was used, a force of 200 N or less was applied. When the foot-operated brake pedal was used, an operation force of 350 N or less was applied.

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

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

TEST RESULTS

Dry Surface Tests

On the ABS-equipped motorcycles, the operator was tasked with braking sufficiently to assure the operation of the ABS.

The measured stopping distance values were corrected to compare data from the speeds of 48 km/h and 128 km/h, except for the BMW F650 data, which was corrected to 48 km/h and 117 km/h, the latter figure limited by that model's top speed of 157 km/h (i.e. 75% of 157 km/h).

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

In the ABS-disabled mode, the stopping distances were less consistent because the rider while modulating the brake force, had to deal with many additional variables at the same time. Up to six runs were allowed for the rider to become familiar with the motorcycle's behavior and to obtain the best stopping distance. Test results from non-ABS motorcycles were noticeably more sensitive to rider performance variability.

The data in Table 2 include the *best* stopping distances obtained without ABS, compared to the *average* braking performance obtained with ABS. The average results were favored for presenting the performance with ABS because the best results could be more representative of threshold braking, whereby the ABS operated for only a portion of the entire test.

Despite being compared to the best stopping distances without ABS, the average results with ABS provided an overall reduction in stopping distance of 5%. The stopping distance reduction was more significant when the motorcycle was loaded (averaging 7%). The greatest stopping distance reduction (averaging 17%) was observed when only the rear foot pedal was applied to stop the motorcycle from 128 km/h.

With respect to the motorcycles equipped with CBS, the benefit of CBS is obvious when comparing rear wheel braking performance (see Table 2). Of the motorcycles tested for this report, only the Honda CBS operates the front wheel brake as well as the rear wheel brake with the application of the rear foot pedal. As a result, application of the rear foot pedal shortened the overall braking distance significantly.

Wet Surface Tests

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

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

For motorcycles not equipped with ABS, the test procedure was the same except that the rider was instructed to apply as much force as required on the brake control device in order to get the shortest stopping distance without losing vehicle control or having any wheel lockup above a speed of 10 km/h. As with the dry surface tests, practically no learning process was required for the operator to achieve the best performance with the operation of ABS. In the ABS-disabled mode, the stopping distances improved as the rider became more familiar and comfortable with the braking system.

Given the same reasoning as presented in for the dry tests, the test results summarized in Table 3 display the *average* results for tests with ABS, and the *best* stopping distance for the tests without ABS. The accumulated data were based on a total of three stops with ABS and three stops without ABS, for each brake scenario being tested (i.e. both brake controls, front brake control only, and rear brake control only).

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

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

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

CONCLUSIONS

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

Without ABS, the rider required numerous attempts to approach the maximum deceleration performance of the motorcycle. With the use of ABS, however, the rider was able to quickly obtain consistent maximum deceleration results, whether the vehicle was loaded or lightly loaded. Despite this advantage, the rider must remain alert because the ABS may not detect dynamic instabilities such as the rear wheel becoming airborne, possibly requiring the operator to reduce the brake control force to prevent a fall. With respect to CBS, its advantage was most evident through shorter braking distances, specifically when braking with the rear wheel only, whereby the CBS activates a portion of the front brake to assist in the deceleration of the motorcycle.

In the real world, the emergency braking maneuver is likely to be an infrequent occurrence. Obtaining a high level of braking performance depends on a multitude of variables including weather conditions, road surface, condition and type of motorcycle brakes and tires, and operator expertise. The testing described above has shown that the operation of the ABS may not be as simple as “slamming on the brakes.” To achieve the best braking performance, the rider must ensure that the rear wheel is on the ground throughout the stop.

However, the results of this testing make it clear that, of the motorcycles tested, those equipped with the anti-lock braking system provide all riders with the advantage of a high level of braking performance at the time of need.

REFERENCES

1. "Motorcycle Brake System Comparison Tests" Transport Canada and National Highway Traffic Safety Administration, report no. NHTSA-2002-11950-3

2. Federal Register of August 14, 2001 Final Rule published by NHTSA amending FMVSS No. 122 Motorcycle Brake Systems (66FR42613, final rule regulatory text at p. 42617). This final rule took effect on August 14, 2002.

Table 2: Dry Surface Braking Results

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

* Top speed of BMW F650 being 157 km/h, its test speed was 117.8 km/h (75% of 157 km/h).

Notes:
(1) Minimal or no ABS operation.

(2) Results most likely to improve with additional test runs.

(3) Average values listed for stops w/ABS, best result values listed for stops w/o ABS.

Table 3: Wet Surface Braking Results

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

(1) Average values listed for stops w/ABS, best result values listed for stops w/o ABS.