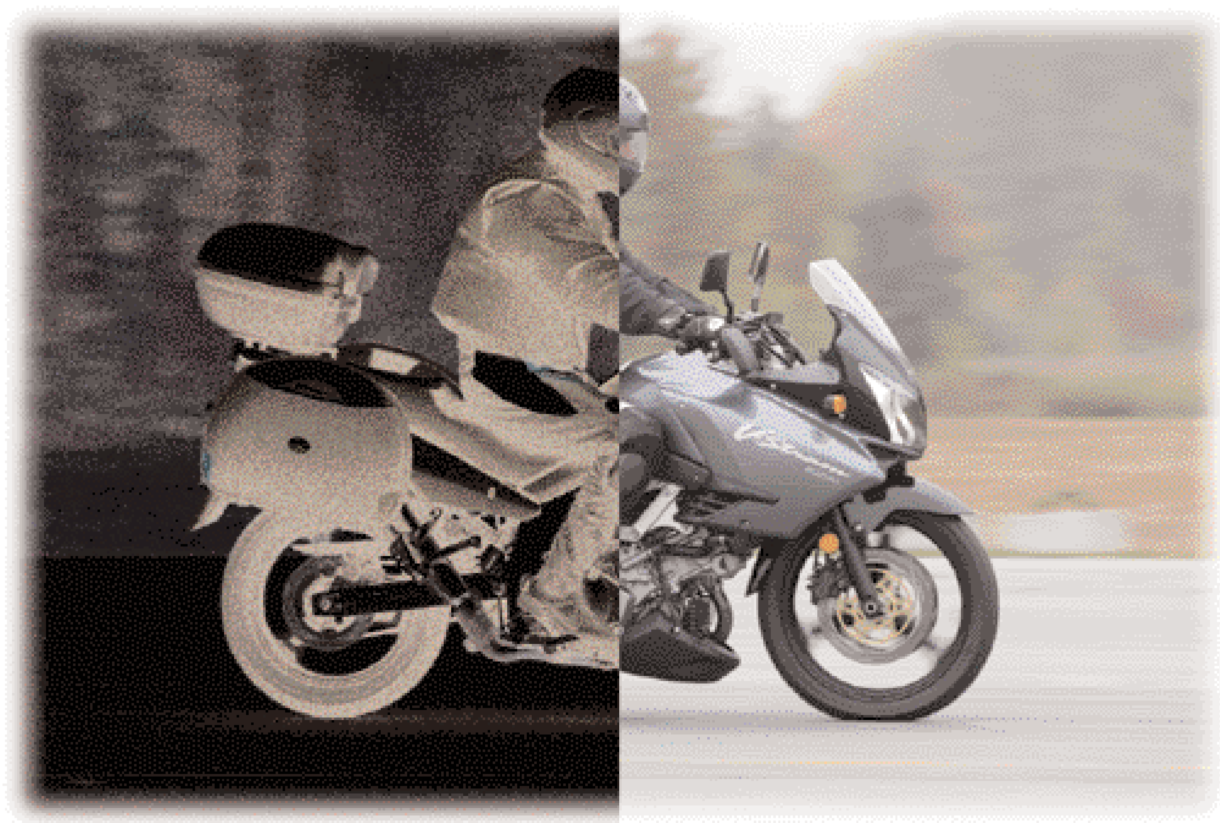
Performance evaluation for various braking systems of street motorcycles



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Introduction

This report covers a series of motorcycle braking tests aimed at measuring the performance of the front brake and of the rear brake compared with using the two brakes simultaneously during intensive braking in a straight line.
This report also covers braking tests performed on motorcycles equipped with anti-lock braking systems (ABS). In addition, it covers the efficiency of certain variants with a shared (integrated) braking system, as well as summarizing the influence of a wet surface and of the addition of a passenger on the global braking properties of a motorcycle.

Independent braking system

On the great majority of current motorcycles the brake for the front wheel and the brake for the rear wheel are activated by separate controls. The front brake is activated by the lever on the right handlebar and controlled by the rider's hand. The rear brake is activated by a pedal mounted close to the right footpeg and is controlled by foot.

In an automobile there is only minor risk in jamming on the brake pedal, but on a motorcycle maximum braking has considerably greater risk and requires much more expertise since the rider must activate two separate braking controls independently but in parallel. The fact that the front brake and the rear brake must be separately activated and modulated in optimum fashion, the front by the hand and the rear by the foot, without locking the wheels underlines the level of difficulty the rider faces. Furthermore, as the rate of deceleration increases, as happens in the case of an emergency stop, weight is transferred progressively to the front wheel.This phenomenon, which is much more accentuated than on an automobile, indicates that available braking effort diminishes progressively on the rear wheel and increases progressively on the front wheel during braking. This is another variable for which the rider must compensate and which raises the index of difficulty.

ABS system (Anti-lock Braking System)

This device prevents the wheels from locking despite the rider's excessive pressure on the braking system. The risk of skidding and of loss of steering is thus eliminated during intensive braking in a straight line. ABS can be applied to either an independent or an integrated braking system. On a motorcycle, this device only plays a significant role in straight-line braking, rather than when the motorcycle is leaned over in a corner. Offered for the first time as standard equipment on a motorcycle in 1988, it is presently far from being in as widespread use as on automobiles.

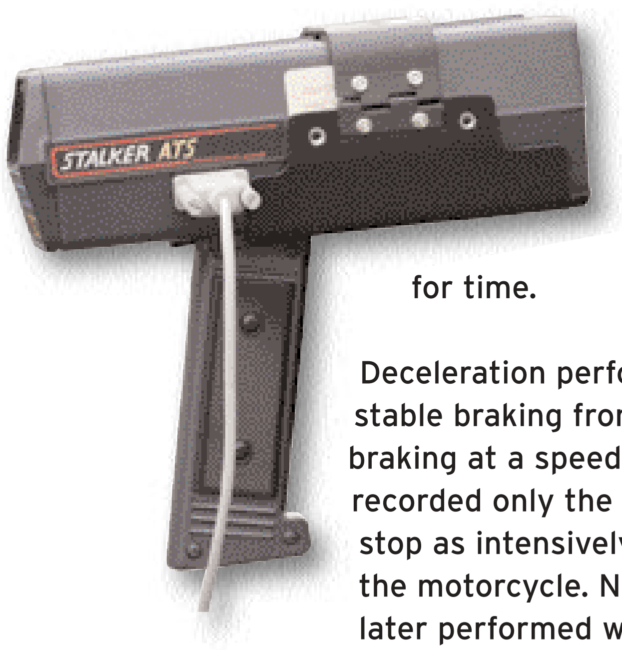
Integrated system

Contrary to an independent system in which the front brake and the rear brake are actuated by separate controls, the integrated system allows one control, usually the pedal for the rear brake, to activate the front brake as well as the rear. The lever mounted on the right handlebar continues to actuate the front brake independently, but in certain cases can also actuate the rear. When the lever and the pedal actuate the brakes for the two wheels simultaneously, the system is described as totally integrated while the braking system in which one of the two wheels is actuated by only one control (lever or pedal), the system is described as partially integrated.

Research method

All the tests took place in the Charlie zone of the PMG Test and Research Centre at Blainville, Que., north of Montreal. Six experienced riders performed a total of 349 braking tests on 10 different motorcycles in two separate sessions, August 9 and 27, 2002.

Experimental apparatus



Data acquisition was performed with the aid of a Toshiba Satellite 3000 portable computer coupled to a Stalker ATS radar gun. With the aid of Stalker ATS software each braking test was continuously recorded, thereby ensuring a precision on the order of one centimetre for distances and one hundredth of a second for time.

Deceleration performance demanded of the riders called for intense and stable braking from 100 km/h to 0. Riders were instructed to initiate their braking at a speed above 100 km/h to ensure that the measurements recorded only the stabilized portion of their stop. They were required to stop as intensively as possible without surpassing their limits or those of the motorcycle. No crashes were experienced. Analysis of the data was later performed with the help of Excel and FileMaker Pro software.

Before each block of tests, riders were instructed as to the type of usage of the brakes they were to perform, whether of both brakes simultaneously or of the front or rear exclusively. Assignment of the three types of braking was made on a rotating basis to compensate for the familiarity and confidence levels of the riders.

Riders were free to choose how they applied the brakes, whether in covered mode or not. Riders also had the latitude to decide to actuate the front brake lever with the number of fingers they chose.

The standard unit of measure for these tests was the G (1G) which equates to an acceleration of 9.8 metres per second per second. Since it was a braking manoeuvre, all the measurements taken were negative.

Dry surface

Solo
Results with an independent system (non-ABS)

Independent (non-ABS)

Control(s) actuated	System(s) actuated	f	Mean Acceleration (-G)	Standard Deviation (-G)	Maximum Acceleration (-G)	Minimum Acceleration (-G)	Braking capacity %
Lever and pedal	front and rear	82	0.774	0.144	0.984	0.417	100
Lever	front	68	0.711	0.107	0.920	0.438	92
Pedal	rear	72	0.425	0.029	0.500	0.370	55

f= number of tests

Use of both brakes
The group of 82 tests conducted on motorcycles equipped with independent braking systems using a combined application of both brakes produced a mean deceleration of −0.774 G with a standard deviation of 0.144 G.

Use of the front brake only
The group of 68 tests conducted on motorcycles equipped with independent braking systems using an application of only the front brake produced a mean deceleration of −0.711 G with a standard deviation of 0.107 G. In this situation the front brake thereby generated 92 % of the total braking capacity of motorcycles equipped with an independent braking system.

Use of the rear brake only
The group of 72 tests conducted on motorcycles equipped with independent braking systems using an application of only the rear brake produced a mean deceleration of −0.425 G with a standard deviation of 0.029 G. In this situation the rear brake thereby generated 55 % of the total braking capacity of motorcycles equipped with an independent braking system.

Notes: *While the maximum braking force was here obtained with the simultaneous application of both brakes, we must note the importance of the braking capacity of the front wheel which can be responsible for more than 90 % of the overall braking capacity of the motorcycle. The fact that locking the front wheel, which provides the steering and equilibriium of the motorcycle, leads almost inevitably to a crash seems to discourage the promotion of intensive use of the front brake in rider training.*

Recommendations

1 - We recommend that motorcycle rider training courses recognize the importance of the front brake during emergency stopping in a straight line. This recognition should be given at both the practical and theoretical level. The duration of explanations and exercises allowed for front wheel braking should be greater than those allowed for the rear.

2 - Authorities responsible for licensing examinations should also recognize this fact by developing tests that will confirm that the candidate has sufficiently mastered the front brake. A practical test leading to the issuing of a motorcycle operator's licence should demonstrate that the candidate is able to generate a minimum intensity of −0.66 G, which is equivalent to a deceleration of 6.5 metres per second per second, from a starting speed on the order of 70 km/h.

Myths to forget

Do not brake the motorcycle too hard to avoid the risk of going over the handlebars.

No application of the front brake, no matter how hard, will project the rider over the handlebars. The greatest risk comes from locking the front wheel, which gives an immediate loss of stability and usually causes a low-side crash.

Before starting emergency braking on a motorcycle you must look in the mirrors to be sure you won't be rear-ended by a car, since a motorcycle can stop much more quickly than a car.

During emergency braking, the rider of a motorcycle must concentrate exclusively on braking since the manoeuvre requires a high level of skill. Based on figures published in specialty magazines, a modern automobile can easily generate –1 G in hard braking, thereby stopping in a shorter distance than a motorcycle.

Dry surface

Solo
Results with an independent system (with ABS)

Independent (withABS)

Control(s) actuated	System(s) actuated	f	Mean Acceleration (-G)	Standard Deviation (-G)	Maximum Acceleration (-G)	Minimum Acceleration (-G)	Braking Capacity %
Lever and pedal	front and rear	26	0.869	0.155	1.009	0.399	100
Lever	front	17	0.725	0.093	0.868	0.558	83
Pedal	rear	20	0.424	0.032	0.526	0.365	49

f= number of tests

Use of both brakes

The group of 26 tests conducted on motorcycles equipped with independent braking systems with ABS using a combined application of both brakes produced a mean deceleration of −0.869 G with a standard deviation of 0.155 G.

Use of the front brake only

The group of 17 tests conducted on motorcycles equipped with independent braking systems with ABS using an application of only the front brake produced a mean deceleration of −0.725 G with a standard deviation of 0.093 G. In this situation the front brake thereby generated 83 % of the total available braking capacity.

Use of the rear brake only

The group of 20 tests conducted on motorcycles equipped with independent braking systems using an application of only the rear brake produced a mean deceleration of −0.424 G with a standard deviation of 0.032 G. In this situation the rear brake thereby generated 49 % of the total available braking capacity.

Notes: *From a safety perspective, an anti-lock device on a motorcycle braking system brings considerable advantages. In a straight-line emergency stop a motorcycle equipped with an independent braking system with ABS can generate forces greater than or equal to a non-ABS system while eliminating any possibility of crashing because of locked wheels.*

During these tests on dry pavement, the motorcycle equipped with such a system peformed equal to or better than motorcycles that were not so equipped. Overall, for the tests involving use of both brakes simultaneously, the motorcycle equipped with ABS generated a mean deceleration 12 % superior to motorcycles without ABS.

Recommendation

3- Faire la promotion des avantages d'un dispositif antiblocage sur le système de freinage d'une motocyclette.

Dry surface

Solo
Results with an integrated system (non-ABS)

Integrated (non-ABS)

Control(s) actuated	System(s) actuated	f	Mean Acceleration (-G)	Standard Deviation (-G)	Maximum Acceleration (-G)	Minimum Acceleration (-G)	Braking Capacity %
Lever and pedal	front and rear	6	0.740	0.075	0.787	0.592	100
Lever	front	5	0.474	0.023	0.494	0.441	64
Pedal	rear	6	0.583	0.022	0.616	0.553	79

f= number of tests

Use of both brakes
The group of 6 tests conducted on motorcycles equipped with integrated braking systems without ABS using a combined application of both brakes produced a mean deceleration of −0.740 G with a standard deviation of 0.075 G.

Use of the front brake only
The group of 5 tests conducted on motorcycles equipped with integrated braking systems without ABS using an application of only the front brake produced a mean deceleration of −0.474 G with a standard deviation of 0.023 G. In this situation the front brake thereby generated 64 % of the total available braking capacity.

Use of the rear brake only
The group of 5 tests conducted on motorcycles equipped with integrated braking systems without ABS using an application of only the rear brake produced a mean deceleration of −0.583 G with a standard deviation of 0.022 G. In this situation the rear brake thereby generated 79 % of the total available braking capacity.

Notes: *The integrated system tries to compensate for the fact that in emergency braking a large number of motorcyclists have a tendency to rely on the rear brake (reflex of pressing on a brake pedal as in an automobile) and under-utilize the front (fear of crashing because of a locked wheel) thereby depriving themselves of a considerable amount of braking capacity. With an integrated system, the action of the brake pedal, acting on both the front and rear wheel, forces use of the front brake and thereby increases braking capacity.*

Dry surface

Solo
Results with an integrated system (with ABS)

Integrated (with ABS)

Control(s) actuated	System(s) actuated	f	Mean Acceleration (-G)	Standard Deviation (-G)	Maximum Acceleration (-G)	Minimum Acceleration (-G)	Braking Capacity %
Lever and pedal	front and rear	10	0.853	0.103	0.983	0.692	100
Lever	front	8	0.756	0.028	0.795	0.714	89
Pedal	rear	3	0.805	0.015	0.818	0.789	94

f= number of tests

Use of both brakes

The group of 10 tests conducted on motorcycles equipped with integrated braking systems with ABS using a combined application of both brakes produced a mean deceleration of −0.853 G with a standard deviation of 0.103 G.

Use of the front brake only

The group of 8 tests conducted on motorcycles equipped with integrated braking systems with ABS using an application of only the front brake produced a mean deceleration of −0.756 G with a standard deviation of 0.028 G. In this situation the front brake thereby generated 89 % of the total available braking capacity.

Use of the rear brake only

The group of 3 tests conducted on motorcycles equipped with integrated braking systems with ABS using an application of only the rear brake produced a mean deceleration of −0.805 G with a standard deviation of 0.015 G. In this situation the rear brake thereby generated 94 % of the total available braking capacity.

Notes: *An integrated system with ABS displayed one of the best braking results while also offering the geatest tolerance of the two most common braking errors (locking the wheels and under-utilizing the front brake).*

Wet surface

Solo
Results with an independent system (non-ABS)

Independent (non-ABS)

Control(s) actuated	System(s) actuated	f	Mean Acceleration (-G)	Standard Deviation (-G)	Maximum Acceleration (-G)	Minimum Acceleration (-G)	Braking Capacity %
Lever and pedal	front and rear	3	0.685	0.073	0.741	0.603	100
Lever	front	2	0.483	0.075	0.536	0.430	71
Pedal	rear	2	0.410	0.022	0.425	0.394	60

f= number of tests

Use of both brakes

The group of 3 tests conducted on a motorcycle equipped with an independent braking system without ABS using a combined application of both brakes on a wet surface produced a mean deceleration of −0.685 G with a standard deviation of 0.073 G.

Use of the front brake only

The 2 tests conducted on a motorcycle equipped with an independent braking system without ABS using an application of only the front brake on a wet surface produced a mean deceleration of −0.483 G with a standard deviation of 0.075 G.

Use of the rear brake only

The 2 tests conducted on a motorcycle equipped with an independent braking system without ABS using an application of only the rear brake on a wet surface produced a mean deceleration of −0.410 G with a standard deviation of 0.022 G.

Notes: *A wet surface reduces overall braking capacity by about 10 % when both brakes are used. Variations on wet surfaces merit further study with more advanced tests and a greater number of them.*

Recommendations

4 - We recommend that motorcycle rider training courses prepare motorcyclists to practise their braking on a wet surface. This recognition should be made at the theoretical level as well as the practical.

5 - Authorities responsible for licensing examinations should also take into account this reality by developing tests that will confirm that the candidate has sufficiently mastered braking on wet surfaces.

Dry surface

Passenger

Control(s) actuated	System(s) actuated	f	Mean Acceleration (-G)	Standard Deviation (-G)	Maximum Acceleration (-G)	Minimum Acceleration (-G)	Braking Capacity %
Lever and pedal	front and rear	5	0.745	0.076	0.868	0.682	100

f= number of tests

The group of 5 tests recorded with motorcycles carrying a passenger during a combined application of both brakes on a dry surface produced a mean deceleration of −0.745 G with a standard deviation of 0.076 G.

Notes: *The presence of a passenger does not seem to have a significant effect on the maximum braking capcity of a motorcycle in a straight line.*

Recommendations

6 - We recommend that motorcycle rider training courses prepare their students to practise their braking with a passenger on board. This recognition should be made at the theoretical level as well as the practical.

7 - Authorities responsible for licensing examinations should also take into account this reality by developing tests that will confirm that the candidate has sufficiently mastered braking while carrying a passenger.

List of motorcycles evaluated for this analysis

Independent braking system without ABS

- Honda CBR929, 2001
- Honda CB900F, 2002
- Honda Valkyrie, 2001
- Honda VFR750, 1991
- Kawasaki Concours, 1990
- Suzuki V-Strom, 2002
- Yamaha FZ1, 2002

Independent braking system with ABS

- Yamaha GTS 1000, 1993

Integrated system without ABS

- Honda Gold Wing 1500, 2000

Integrated system with ABS

- Honda Gold Wing 1800, 2002

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