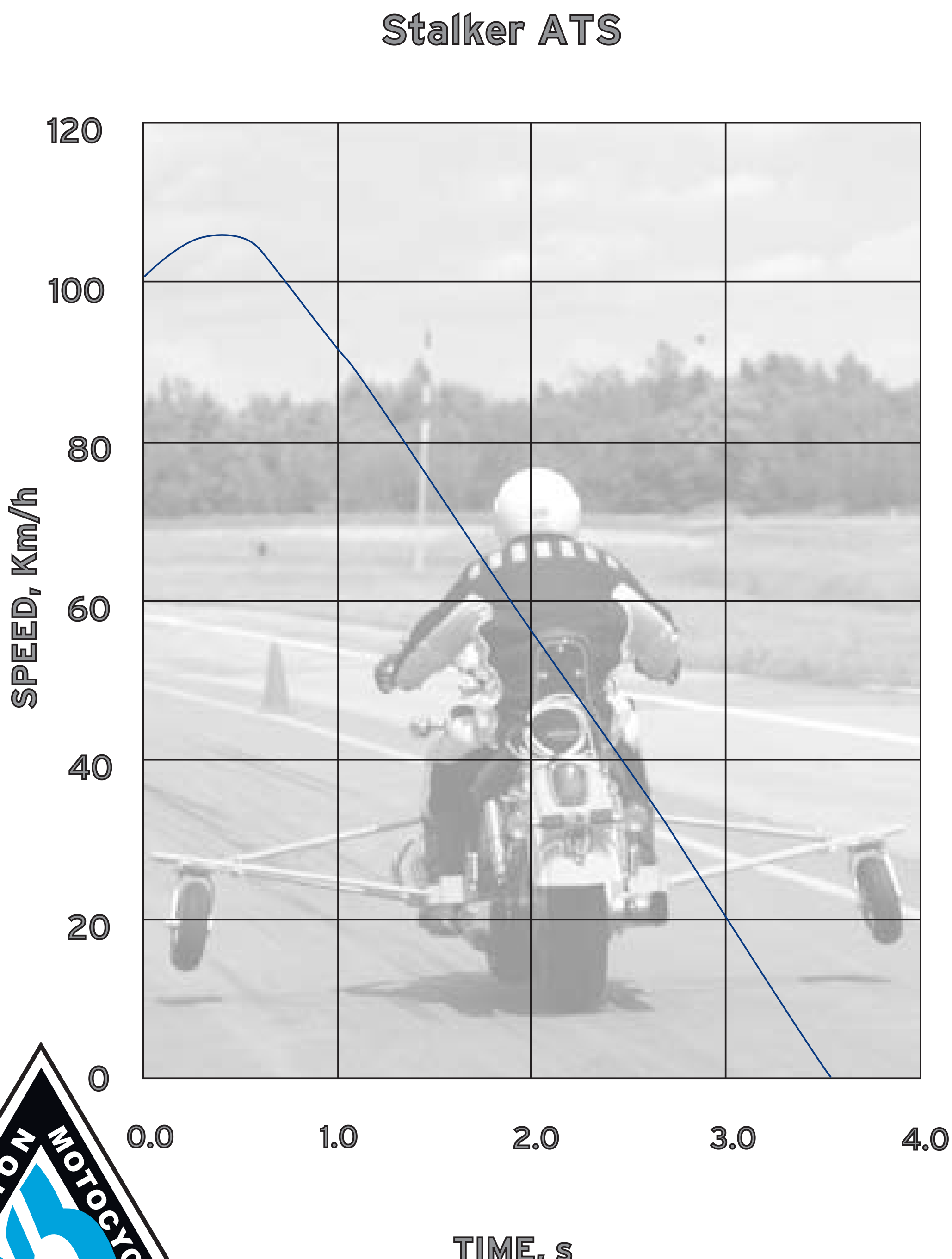
Task analysis for intensive braking of a motorcycle in a straight line



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ELEMENTS OF EMERGENCY BRAKING

Straight-line emergency braking of a motorcycle depends not just on the intensity of braking itself but also on the choice of manoeuvres, the rapidity and the sequence of operations which preceded it.

OBJECTIVE OF THE RESEARCH

The objective of this research was, based on the appropriate tests, to recommend a standard procedure for a successful emergency stop. This sequence would cover the ideal moment for closing the throttle, for application of the rear brake, for application of the front brake and for the pertinence and the timing of using the clutch.

SEQUENCES PRESENTLY PROPOSED

For the most part, the methods presently described or taught about the steps to follow for emergency braking of a motorcycle are very general, if not superficial or simplistic. They were designed several years ago and do not take into account technical evolution of braking capacity and of tires on modern motorcycles. And also, they are not constant.

CONVENTIONAL BRAKING SYSTEM

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

ABS AND INTEGRAL SYSTEMS

Although anti-lock braking systems (ABS) that make it impossible to lock the wheels while braking in a straight line have been available for motorcycles for several years, the great majority of motorcycles presently in use are not so equipped.

The same applies to integral braking systems which equip only a tiny minority of the motorcycles available on the market. This system provides a control, generally the pedal for the rear brake, that also actuates a portion of the front brake as well as the rear brake. The lever mounted on the right handlebar continues to independently actuate a part of the front braking system, but in certain cases can also actuate the rear brake.

DIFFICULTY OF APPLICATION IN A CONVENTIONAL SYSTEM

If with an automobile there is little risking in stamping on the brake pedal, maximum braking of a motorcycle poses greater risks and demands greater expertise since the rider must simultaneously manage two independent braking systems in parallel. The fact that the front brake and the rear brake must be operated and modulated in a separate and optimal manner, the front by the right hand and the rear by the right foot, without causing a locked wheel underlines the difficulty the rider must face.

Also, during deceleration, such as in the case of emergency braking, load is transferred progressively to the front wheel. This phenomenon, which is more pronounced on a motorcycle than on an automobile, implies that the available braking force 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 increases the difficulty of execution.

RISKS ARISING FROM A LOCKED FRONT WHEEL

Locking of the front wheel must be avoided at all costs during hard braking because it leads almost automatically to a loss of directional control and a sideways crash if it persists longer than a tenth of a second. Fear engendered by this physical reality means that the majority of motorcyclists under-utilize the capacity of their front brake, especially at the start of braking. Thus it is of paramount importance to become proficient at the start of braking because the distance travelled is relatively greater than at the end of braking.

TRANSFER DELAY

Faced with his reality, it is generally recommended to use the front brake firmly once the load has been transferred to the front tire. Certain instructors recommend using the rear brake pedal to initiate the transfer of mass whereas others maintain that the act of completely closing the throttle is enough to initiate transfer.

RISKS ARISING FROM A LOCKED REAR WHEEL

While locking the rear wheel is less catastrophic than locking the front, it always leads to an increase in braking distance and often causes a slide through loss of lateral traction. When the slide is pronounced and the rider releases the rear brake pedal, the rear wheel suddenly regains its traction. Rapid realignment of the rear wheel on its yaw axis can then alarm the rider to a greater or lesser extent, possibly leading to a loss of control or a crash.

Based on the premise that a locked wheel offers even greater braking force than a rotating wheel, some observers propose, in case of locking the rear wheel, to not release the brake pedal but continue braking, while concentrating on braking with the front wheel and trying to control the sliding of the rear wheel. Adherents to this approach even recommend practising deliberately locking the rear wheel for training purposes.

NON-USAGE OF THE REAR BRAKE

Finally, another school of thought recommends not using the rear brake at all in order to avoid the risk of locking it and to allow the rider to concentrate on using the front brake. A previous study has demonstrated the necessity of using the rear brake.

TEST CONDITIONS

We retained the services of eight experienced riders. Two motorcycles were used, one sport machine and one custom cruiser, both equipped with outriggers to allow the riders to reach or surpass the braking limits of the motorcycles. For the compilation of the preliminary results, more than 820 tests were recorded. From this data pool, 298 tests corresponding to the selection criteria were retained for compilation of the final report. In order to be selected, a test had to post intensive and continuous braking beginning from a speed equal or superior to 100 km/h preceded immediately by a period of acceleration.

All the tests were performed on the Charlie track of the PMG test and research centre at Blainville, Que., north of Montreal, during eight separate day-long sessions.

TEST APPARATUS

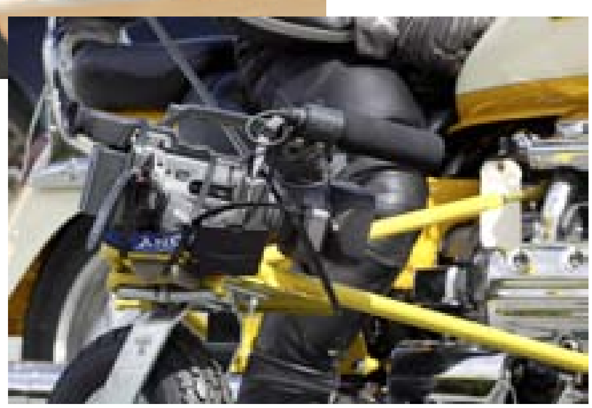
Data acquisition for each braking test was performed with the aid of a portable Toshiba Satellite 300 computer coupled to a Stalker ATS radar unit. Using Stalker ATS software each braking test was recorded with a precision on the order of one centimetre for distance and one hundredth of a second for time.

Both motorcycles were equipped with a series of monitors for signals such as complete closing of the throttle, use of the front brake lever, use of the clutch lever, use of the rear brake pedal and half-travel of the front suspension. These signals were sent to an NI PCI 6602 data card mounted to a full-size Macintosh G4/867 computer carried on board the motorcycle.

The precision of the times recorded was on the order of one tenth of a microsecond (10-7 seconds), while the values retained for analysis were rounded to a thousandth of a second (0.001). Data were acquired by means of a Labeview 6 Developer Edition utility (Mac) and an in-house acquisition program.

MERGER OF DATA

Information collected by the two independent apparatus was amalgamated and organized on a database managed by Filemaker Pro software. Data analysis was performed with the aid of this program as well as with Excel software.



POSTULATE ON USAGE OF THE REAR BRAKE

Emergency braking on a motorcycle equipped with a conventional braking system must involve use of the rear brake, even though it has a less important role than the front brake. It plays a role in the first instants of braking before the rear wheel becomes unloaded through weight transfer. A series of test we conducted in 2003 (Performance Evaluation For Various Braking Systems of Street Motorcycles) showed that use of both brakes generates a mean deceleration of -0.774 g compared with -0.711 g without using the rear brake.

The unit of measurement g corresponds to an acceleration of 9.8 metres per second per second.

The 16th best stop of the 298 tests in the collection was made by a rider who did not use the rear brake. He stopped in 38.45 metres compared with the mean distance of 41.71 metres for the whole of the 298 tests. This test was not retained for the tables employed for recommendations.

FREE BRAKING PROCEDURE

Riders were required to brake as hard as possible while using the controls in a sequence with which they felt most at ease.

Riders were free to choose how to apply the brakes, whether covered or not. Riders also had the latitude to squeeze the front brake lever with the number of fingers they wanted.

This freedom of choice meant that some of the recorded tests were done by one rider who did not use the rear brake and by another who pulled in the clutch lever just before reaching a complete standstill of the motorcycle. These tests were not included in the tables employed for recommendations.

COULOMB'S LAW

According to Coulomb's law, the friction of a sliding object increases with the force applied. When a greater force is applied to a tire, the suppleness of the rubber allows the surface in contact with the ground to conform better with the irregularities of the pavement, and the area in contact with the ground to increase through deformation of the tread. The limitation is that deformation of the rubber is not linear according to the force applied and therefore there is a limit to this effect. It also explains why a larger tire offers, at its limit, greater traction.

JUSTIFICATION FOR A STANDARD PROCEDURE

The two motorcycles used for these experiments were of different types: a 2001 sport model Honda CBR929RR and a 1999 custom style Honda GL1500 Valkyrie. In terms of braking performance there was no significant difference between them. The mean stopping distance in 214 tests of the sport model was 41.67 metres from 100 km/h compared with a mean of 41.83 metres in 84 passes of the custom machine. These results convince us that a standard emergency braking procedure is possible and valuable despite the weight differences among motorcycles.

EFFECTS OF DECELERATION FORCE

The mean deceleration for the group of 298 passes braking from 100 km/h to zero wa -0.898 g in a mean time of 3.18 seconds. During these more than 3 seconds, the rider had to manage his braking while subjected to a considerable deceleration force against his arms and hands which must in large measure support his upper body. A simulator designed to recreate this force would have to incline the motorcycle on its front wheel at an angle of 64 degrees.

THE EQUILIBRIUM STAGE

Each emergency braking manoeuvre is preceded by a stage of stabilizing the motorcycle. Although it may be very short, it is no less important despite the fact that it is little covered in the literature. Even when the motorcycle gives the impression of rolling in a straight line, the rider makes constant adjustments to maintain equilibrium among different forces and the chosen trajectory. At the moment of emergency braking, this equilibrium must be perfect and be maintained for the length of the braking manoeuvre.

PRISONER OF POSTURE

Once the emergency braking procedure is started, because of the forces engendered by deceleration on the arms and hands, the rider is a prisoner of his choice of the number of fingers employed on the front brake lever. During the course of intensive braking he must not modify the position of his fingers.

DISTANCE VERSUS TIME

<u>The objective of emergency braking must be to reduce as much as possible his speed in the shortest distance possible and not in the least elapsed time.</u> Although there is a correlation between braking distance and time, it is not absolute. Thus the quickest stop from 100 km/h recorded during these tests lasted only 2.70 seconds but covered 37.68 metres. The shortest stopping distance recorded was 36.95 metres in an elapsed time of 2.75 seconds. This slight difference highlights the importance of an effective start to the braking procedure at the moment when the distances travelled are greatest.

USE OF THE CLUTCH

Downshifting: *Should one downshift during emergency braking?*

Some observers maintain that it is preferable to downshift during hard braking in order to be in a position to accelerate again if the situation demands it. Others claim that during an emergency stop the rider must concentrate exclusively on braking and that downshifting can only increase braking distances.

We devoted an entire day (June 20, 2003) to this variable during which we recorded 77 tests with two different riders on the same motorcycle.

The mean stopping distance for 31 tests during which the riders were instructed to downshift was 43.17 metres compared with the general average of 41.71 metres for the group of 298 tests.

TABLE 1 : USE OF THE CLUTCH

		Deceleration	Distance	Time	Distance	Time
			100 km/h to 0		80 km/h to 0	
Variable	N	(G)	metres (m)	secondes (s)	metres (m)	secondes (s)
With downshifting	31	-0.891	43.17	3.21	24.97	1.81
Clutch engaged	35	-0.889	41.51	3.21	24.50	1.78
Clutch disengaged	11	-0.929	39.95	3.08	23.41	1.72
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CLUTCH ENGAGED

With the goal of reducing the chance of locking the rear wheel and its negative consequences, certain observers suggested not declutching during a hard stop. The rear wheel thus remaining coupled mechanically to the engine is less susceptible to lock.

The mean braking distance recorded over 35 passes with the clutch engaged was 41.51 metres.

CLUTCH DISENGAGED

In the 11 passes for which the rider was instructed to declutch, that is to pull the clutch lever and disengage the rear wheel from the engine, the mean stopping distance was 39.95 metres.

RECOMMENDATION CONCERNING THE CLUTCH

In light of these figures we recommend completely declutching during an emergency stop.

ELIMINATION OF VARIABLES

Knowing already that use of the rear brake is necessary for effective emergency braking and that pulling in the clutch lever all the way leads to the shortest braking distances, we concentrated our efforts on tests involving these two factors in order to compare them with the group of 298 tests.

TABLE 2 : SUMMARY OF 298 TESTS	
Number of tests (N)	**298**
Chronology	**Seconds**
Time to completely close the throttle	0.0000
Time to apply rear brake	0.2217
Time to apply front brake	0.2278
Time to declutch	1.0679
Time to compress front suspension to half-travel	0.6237
Mean deceleration	**G**
Mean deceleration from 100 km/h to 0	-0.8982
Distance travelled	**Metres**
Total distance 100 km/h to 0 in metres (m)	41.7072
Total distance 80 to 20 km/h in metres (m)	24.3237
Elapsed time	**Seconds**
Total time from 100 km/h to 0 in seconds (s)	3.1830
Total time from 80 to 20 km/h in seconds (s)	1.7694
Reaction time (seconds)	**Seconds**
Accelerator - rear brake	0.2217
Rear brake - front brake	0.0061
Front brake - declutch	0.8401
Total delay	1.0769

For the group of 298 tests the mean braking distance (100 km/h to 0) was 41.7072 metres with a mean deleration time of 3.1830 seconds. The mean deceleration rate was -0.8982 g. On average, the rear brake came into operation 0.2217 seconds after closing the throttle, the front brake 0.0061 seconds later and the clutch 0.8401 seconds after that.

One will note that the general sequence for this table shows first closing the throttle, then an almost simultaneous usage of the rear and front brakes before declutching almost a second later. This table must be adjusted considering that one of the riders habitually did not use the rear brake while another only pulled in the clutch lever at the completion of braking.

TABLE 3: SUMMARY OF TESTS INVOLVING REAR BRAKING AND DECLUTCHING

Summary of tests
- with omission of tests recording an elapsed time for declutching of more than 1 second
- with omission of tests recording an elapsed time for application of rear brake of more than 1 second

Number of tests (N)	**172**
Chronology	**Seconds**
Time to completely close throttle	0.0000
Time to apply rear brake	0.0710
To to declutch	0.1396
Time to apply front brake	0.1454
Time to compress front suspension to half-travel	0.4986
Mean deceleration	**g**
Mean deceleration from 100 km/h to 0	-0.8941
Distance travelled	**Metres**
Total distance 100 km/h to 0 in metres (m)	41.8129
Total distance 80 to 20 km/h in metres (m)	24.3149
Elapsed time	**Seconds**
Total time from 100 km/h to 0 in seconds (s)	3.1967
Total time from 80 to 20 km/h in seconds (s)	1.7670
Reaction time (seconds)	**Seconds**
Accelerator - rear brake	0.0710
Rear brake - declutch	0.0686
Declutch - front brake	0.0058
Total delay	**0.1454**

If we eliminate from this total pool of 298 tests those in which the rider took more than one second to operate the rear brake as well as to pull the clutch lever, we have 172 tests showing a means braking distance (100 km/h to 0) of 41.8129 metres with a mean time for deceleration of 3.1967 seconds. The mean rate of deceleration was -0.8941 g. On average, the rear brake came into operation 0.0710 seconds after complete closing of the accelerator, the clutch 0.0686 seconds later and the front brake 0.0058 seconds after that.

The sequence for this table shows closing the throttle, use of the rear brake, then almost simultaneously declutching and use of the front brake. The average stopping distance is similar to that of the group of 298 tests, but greater by 10.57 centimetres.

TABLE 4: SUMMARY OF THE 30 BEST TESTS INVOLVING REAR BRAKING AND DECLUTCHING

Summary of the 30 best tests
- with omission of tests recording an elapsed time for declutching of more than 1 second
- with omission of tests recording an elapsed time for application of rear brake of more than 1 second

Number of tests (N)	**30**
Chronology	**Seconds**
Time to completely close throttle	0.0000
Time to apply rear brake	0.0712
Time to apply front brake	0.1567
Time to declutch	0.2090
Time to compress front suspension to half-travel	0.3401
Mean deceleration	**g**
Mean deceleration from 100 km/h to 0	-0.9713
Distance travelled	**Metres**
Total distance 100 km/h to 0 in metres (m)	38.3510
Total distance 80 to 20 km/h in metres (m)	22.4167
Elapsed time	**Seconds**
Total time from 100 km/h to 0 in seconds (s)	2.9287
Total time from 80 to 20 km/h in seconds (s)	1.6307
Reaction time (seconds)	**Seconds**
Accelerator - rear brake	0.0712
Rear brake - front brake	0.0855
Front brake - declutch	0.0523
Total delay	**0.2090**

This table represents the 30 tests with the shortest stopping distance and during which riders cut the throttle, used the two brakes and pulled the clutch lever at the start of braking instead of at the point of the motorcycle reaching a standstill.

The mean braking distance (100 to 0 km/h) for these 30 best tests was 38.3510 metres with a mean elapsed time of 2.9287 seconds. The average deceleration was -0.9713 g.

On average, the rear brake came into operation 0.0712 seconds after complete closing of the throttle,the front brake 0. 0855 seconds later and declutching 0.0523 seconds after that.

IDEAL SEQUENCE

These figures indicate that the ideal sequence for the most effective emergency braking possible is to successively close the throttle, apply the rear brake, apply the front brake and declutch completely.

A FEW SECONDS OF AUTOMATISM

We quickly realized during these tests that the load imposed on the rider during hard braking is immense. An emergency stop from 100 km/h lasts more or less four seconds; basically, one second for reaction and stabilization and three seconds of braking. During these four seconds the rider undergoing considerable physical stress acts in a conditioned manner. In an emergency, the rider performs unconsciously but more quickly and less well what he does habitually in more normal situations.

BRAKING THROUGH HABIT

Pierre Savoie, chief instructor of driver training for BMW Canada, explains the matter by saying, "According to Dr. Bruce Lipton of Sanford University in California, our conscious mind can process 2,000 bits of information per second, while our subconscious can process 4,000,000,000. It's not necessarily limited to reflexes, but to the deeply rooted habits of human beings."

INGRAINED HABITS

In our opinion, the only way for a rider to achieve true proficiency in straight-line emergency braking of a motorcycle is to practise long enough and hard enough to make the procedure a matter of habit.

IDEAL BRAKING

The rider observes a situation that demands emergency braking.

1 Deceleration
He completely closes the throttle and applies the rear brake.

2 Equilibrium stage
He stabilizes the assemblage of rider/passenger with the motorcycle so as to ensure that all are in equilibrium and perfectly vertical while travelling in a straight line. In this very short space of time the rider may lightly adjust his steering. If the motorcycle is moving in a straight path just before braking, this step may be very short. Simultaneously, he straightens his torso and head if he has been crouched and braces his arms, adjusts the position of his fingers and hands, places more load on the footrests and applies pressure to the rear brake pedal.

If there is any straightening of the torso, wind pressure in itself will produce deceleration, accentuated by the rider's release of the accelerator. Pressure of the right foot on the rear brake pedal will slow the rear wheel, which will have the effect of compressing the rear suspension and thereby slightly lowering the centre of gravity of the whole. At this stage, before the majority of the weight bearing on the rear wheel is transferred to the front, the rear brake has its greatest effect which is soon to diminish.

3 Braking
Simultaneously, the rider squeezes the front brake lever with the appropriate pressure and pulls the clutch lever completely in. He concentrates primarily on the front brake lever pressure and secondarily on the rear brake pedal pressure.

4 Adjustment
The rider adjusts the intensity of braking while concentrating on the front lever pressure.

DEBA SEQUENCE

1 Deceleration
- Completely close the throttle
- Apply the rear brake

2 Equilibrium
- Place the bike vertical
- Brace arms and legs
- Straighten torso
- Position fingers and feet

3 Braking
- Apply appropriate pressure ot the front brake
- Declutch completely

4 Adjustment
- Adjust front brake pressure
- Adjust rear brake pressure

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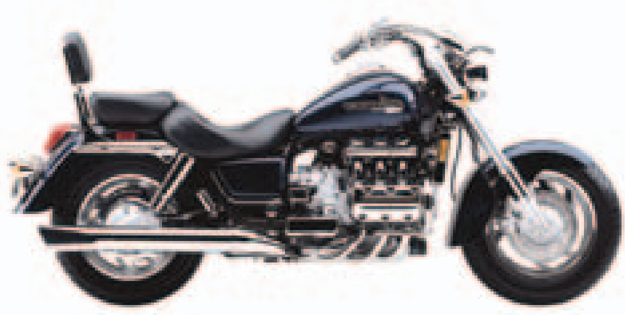
FICHES TECHNIQUES

HONDA CBR929RR

Brand: Honda
Model/year: CBR929RR FireBlade/2001
Engine: Four cylinder inline four-stroke, liquid-cooled
Valve gear: Double overhead cams (DOHC) driven by chain with four valves per cylinder
Power: 129.1 hp at 10,500 rpm
Torque: 92.7 N-m (68.4 lb-ft) at 9,000 rpm
Displacement: 929 cc
Bore and stroke: 74.0 x 54.0 mm
Compression ratio: 11.3:1
Fuel delivery: Injection, 40 mm throttle bodies
Transmission: Six-speed gearbox, 1st 2.692; 2nd 1.933; 3rd 1.600; 4th 1.400; 5th 1.286; 6th 1.190; primary reduction 1.521; final reduction 2.687
Final drive: Chain, drive sprocket 16 teeth, driven sprocket 43 teeth
Suspension: Telescopic inverted front fork with 43 mm tubes, adjustable for preload, compression and rebound; single rear hydraulic damper, 9 adjustable positions for preload, compression and rebound
Wheelbase: 1,400 mm (55.1 in.)
Rake/trail: 23.5 degrees/97 mm
Brakes: Double 330 mm front stainless steel discs with four-piston calipers, single 220 mm rear stainless steel disc with double-piston caliper
TIres: Bridgestone BT010F or Michelin Pilot Sport 120/70ZR17 front; Bridgestone BT010R or Michelin Pilot Sport 190/50ZR17 rear
Battery: 12V - 8.6 A-H
Alternator and starter: 0.421 kW at 5,000 rpm; electric
Dry weight: 172 kg (379 lb)
Load capacity: 164 kg (362 lb) including rider, passenger and accessories
Seat height: 815 mm (32.1 in.)
Fuel capacity: 18 L (3.95 Imp. gal.)
Fuel requirement: Unleaded 86 octane [(Research Index) + (Motor Index) ÷2] or greater
Consumption: 6.6 L/100 km (43 mpg)
Range: 274 km (170.2 mi.)
Length overall: 2,065 mm (81.3 in.)
Width overall: 680 mm (26.8 in.)
Height overall: 1,125 mm (44.3 in.)
Ground clearance: 130 mm (5.1 in.)

HONDA GL1500 VALKYRIE



Brand: Honda
Model/year: GL1500C Valkyrie/1999
Engine: Six cylinder opposed four-stroke, liquid-cooled
Valve gear: Sngle overhead cams (SOHC) driven by belt with two valves per cylinder
Power: 91 hp at 10,500 rpm
Torque: 92.7 N-m (68.4 lb-ft) at 8,500 rpm
Displacement: 1,520 cc
Bore and stroke: 71.0 x 64.0 mm
Compression ratio: 9.8:1
Fuel delivery: Six carburetors, 28 mm diameter
Transmission: Five-speed gearbox, 1st 2.666; 2nd 1.722; 3rd 1.291; 4th 1.000; 5th 0.805; 6th 1.190; primary reduction 1.591; secondary reduction 0.971; final reduction 2.833
Final drive: Shaft

Suspension: Telescopic inverted front fork with 45 mm tubes; dual rear hydraulic dampers, 5 adjustable positions for preload

Wheelbase: 1,689 mm (66.5 in.)
Rake/trail: 32 degrees/152 mm
Brakes: Double 296 mm front stainless steel discs with double-piston calipers, single 316 mm rear stainless steel disc with double-piston caliper
TIres: Dunlop D206F 150/80R17 front; Dunlop D206180/70R16 rear

Battery: 12V - 12 A-H
Alternator and starter: 0.546 kW; electric
Dry weight: 309 kg (681 lb)
Load capacity: 180 kg (397 lb) including rider, passenger and accessories
Seat height: 729 mm (28.7 in.)
Fuel capacity: 20 L (4.40 Imp. gal.)
Fuel requirement: Unleaded 86 octane [(Research Index) + (Motor Index) ÷2] or greater
Consumption: 7.27 L/100 km (43 mpg)
Range: 370 km (230 mi.)
Length overall: 2,525 mm (99.4 in.)
Width overall: 980 mm (38.6 in.)
Height overall: 1,185 mm (46.7 in.)
Ground clearance: 155 mm (6.1 in.)