

Exploratory Study of an Airbag Concept for a Large Touring Motorcycle: Feasibility Verification

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ABSTRACT

Based on the injury assessment method established by ISO/CD 13232 and including neck injury assessment, which had not been established previously, the prototype airbag system was evaluated using full scale impact tests in seven configurations and computer simulation of 200 impact configurations, which calculate the process of dummies contacting the ground.

The GL1800 was used for this study; previous studies used the predecessor large touring motorcycle (GL1500). Furthermore, in addition to the assessment specified in ISO/CD 13232, tests using other configurations and other rider conditions were conducted. It was judged from the results obtained that an airbag system for a large touring motorcycle, like the GL1800, is feasible.

1. Introduction

Honda has conducted research aimed at enhancing the protection of motorcycle riders since the 1960s⁽¹⁾. Recently, research has been directed towards the possibility of fitting airbags on motorcycles, as discussed below.

A prototype airbag system, which included a sensor system, was mounted on a large touring motorcycle, the GL1500, and its rider protection performance was evaluated based on ISO13232⁽²⁾. The results of a series of full scale impact tests and computer simulations showed, that while the system could lead to the possibility of an increase in injuries in some impact configurations, it could help reduce rider injuries overall⁽³⁾.

Concern over a possible increase in injuries was generated by analysis of measurements of neck injuries due to the airbag causing the test dummy to make contact with the ground head-first. This issue was addressed by increasing the size of the airbag⁽⁴⁾.

The majority of the differences in injury type, recorded in tests with and without an airbag, were generated when the dummy made contact with the ground. Therefore, Honda developed a computer

simulation technique covering the aspect of ground impact. A computer simulation was developed with a high degree of accuracy that is able to reproduce the motion of the dummy up to the time of its contact with the ground⁽⁵⁾. Airbag research was furthered by fitting a prototype airbag system on a large scooter-type motorcycle with a different frame design to that of the large touring motorcycle. Full scale impact tests were conducted using part of ISO 13232, and the results indicated that an airbag employing the same design concepts as the airbag used on the large touring motorcycle was also potentially feasible for the large scooter-type motorcycle⁽⁶⁾.

While these research projects on the feasibility of an airbag system for motorcycles were being conducted, a standard for evaluation of neck injuries, which had previously been unavailable, was established in ISO/CD 13232. In addition, Honda had developed a computer simulation technique enabling the range for the assessment of injuries to be extended to the point at which the dummy makes contact with the ground. These advances have made it possible for researchers to evaluate rider protection devices more comprehensively.

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This paper will discuss the results of a series of evaluations of the airbag system for large touring motorcycles, like the GL1800, based on these newly established methods.

2. Concept of Airbags for Large Motorcycles

Figure 1 shows the fatal motorcycle accidents data in Japan⁽⁷⁾. These results show that:

- The majority of fatal injuries (64%) occur in frontal impacts.
- The majority of rider injuries (87%) are caused by impact with the object the motorcycle collided with or the ground rather than with the motorcycle itself.
- The majority of fatal injuries (87%) occur to the upper half of the body.

From this statistical data, the typical fatal injury scenario can be defined as: One in which the rider separates from the motorcycle as a result of a frontal impact, strikes the opposing vehicle or the ground with his or her upper body, and sustains a fatal injury. On this basis, Honda established the following concept for its motorcycle airbag: To reduce the speed of separation of the rider from the motorcycle in the forward direction during a frontal impact by absorbing the kinetic energy of the rider, to help reduce the level of injuries sustained upon impact with the opposing vehicle or the ground. In addition, the following factors were considered based on previous research:

- Support of the airbag (upon which the rider exerts a horizontal load) by the motorcycle frame (i.e. in a frontal impact, with a passenger vehicle with a hood, the airbag should function without being supported by the hood of the opposing vehicle).
- The effectiveness of the airbag should be maintained as much as possible during a pitch, yaw and roll, typical of motorcycle motion in a frontal impact.

3. Test Motorcycles Fitted with Prototype Airbag System

Figure 2 shows a test motorcycle fitted with a prototype airbag system. The motorcycle is the GL1800. The main specifications of the motorcycle are shown in Table 1.

Table 2 shows the specifications of the airbag and the inflator. The airbag and retainer box were redesigned for use on the GL1800. The design of the prototype airbag reflects the results of previous research in a variety of areas: the capacity is larger, the design of the overall shape is superior, the shape of the rear of the airbag has been altered and a support belt has been used to connect the rear of the bag to the frame of the motorcycle. The time required for

deployment of the airbag is approximately 45 msec. A sensor system judges whether to deploy the airbag using the logic shown in Fig. 3 on the basis of the deceleration degree in the vicinity of the front wheel axis (hereinafter referred to as deceleration of the front wheel system).

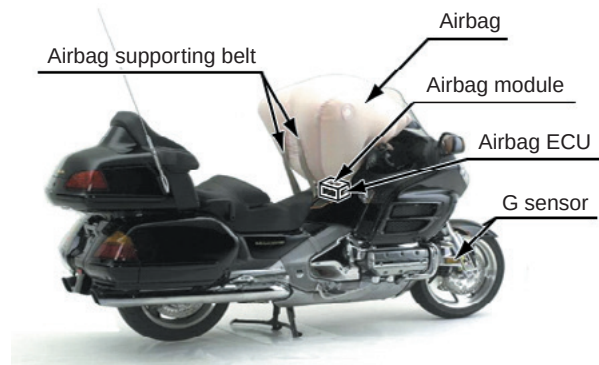


Fig. 2 Prototype airbag system installed on the GL 1800 motorcycle

Table 1 Specifications of test motorcycle

Manufacturer	Honda
Model	GL1800
Year	2000-2003
Mass (average) (empty, as tested no airbag) (kg)	367
Mass (average) (empty, as tested with airbag) (kg)	375
Overall length (mm)	2 635
Overall width (mm)	945
Overall height (mm)	1 455
Wheelbase (mm)	1 690
Type	Touring

Table 2 Specifications of prototype airbag

Volume (Net, inflated) (Liters)	157
Height × Width × Length (mm)	750 × 720 × 640
Diameter of vent holes (mm)	45 (× 2 holes)
Rear shape	Foams a concave "V"
Airbag mounting	To module box To motorcycle frame under the seat, via two connecting belts
Inflator type	Pyrotechnic; Passenger car type
Inflating pressure (kPa)	495

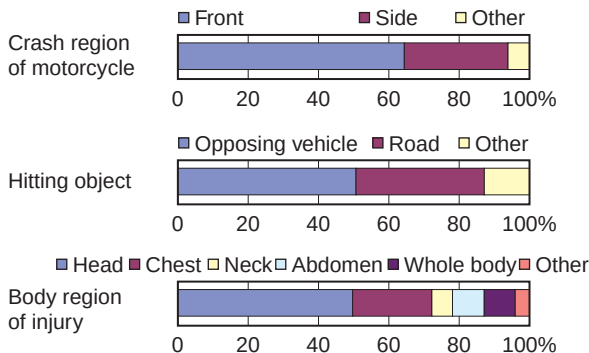


Fig. 1 Fatalities of motorcycle accidents in Japan

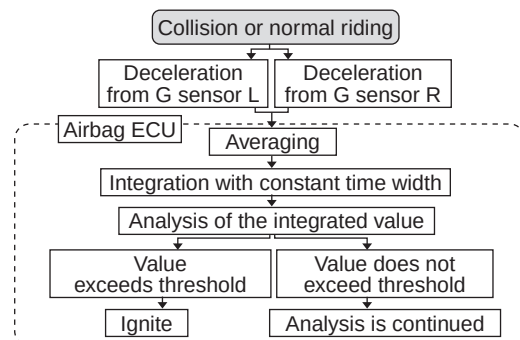


Fig. 3 Decision flow for airbag deployment

4. Sensor System Settings

4.1. Study of Impact Conditions for Deployment of Airbag

Full scale impact tests were conducted using the base motorcycle to study the conditions of frontal impacts resulting in the separation of the rider from the motorcycle in a forward direction. Each test was studied to enable deployment of the airbag during these crash events. The 1998-2001 Honda Accord 4-door with Japanese specifications, as shown in Table 3, was used as the opposing vehicle during impact testing. The rider dummy was a Motorcyclist Anthropometric Test Device (MATD) specified in ISO/CD 13232. Table 4 shows impact conditions and test results. Separation of the dummy from the motorcycle in a forward direction occurred at impact speeds of 35 km/h, but not at 25 and 30 km/h. From these results, it was judged that the airbag should deploy at 35 km/h and above, in front and side impact configurations. The degree of deceleration in the sensor unit was measured for use as base data, for developing the judgment logic and setting the threshold values as discussed below.

4.2. Study of Deceleration of Sensor Unit in Conditions for Non-deployment of Airbag

Other than in the event of an accident, the airbag should not deploy under normal running and handling conditions, including rough roads. To simulate conditions in which the airbag should not deploy, tests were conducted running the motorcycle over steps, on roads with depressions, and on rough roads. The front wheel was also dropped from a “wheelie” position. In addition, the impact on the front wheel when the motorcycle is dropped from the platform of a truck during cargo handling operations was simulated, and the front forks were subjected to impact from a hammer. The degree of deceleration in the sensor unit under these running and handling conditions was measured and used as base data in the development of the judgment logic, and in the setting of the threshold values.

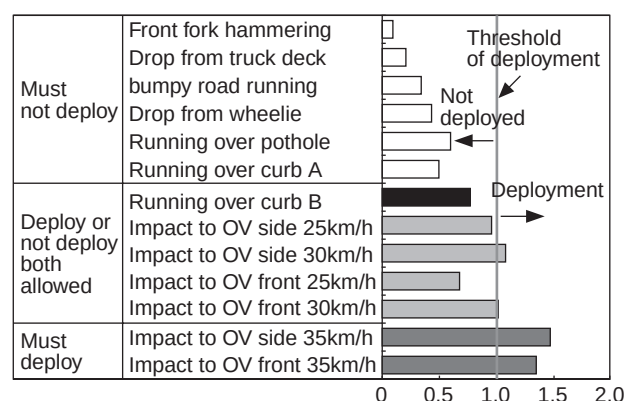


Fig. 4 Decision of deployment by integrated impact deceleration

4.3. Development of Collision Judgment Logic and Setting of Threshold Values

The collision judgment logic (shown in Fig. 3) and the threshold values were decided based from the study of data on deceleration in the sensor unit during impact conditions in which the airbag should deploy, and in running and handling conditions in which it should not deploy. Figure 4 shows the performance of the logic in determining deployment and non-deployment. This figure shows the ratio of threshold values - predetermined values for the judgment to deploy - to the maximum computed values, in each case of deployment or non-deployment. As the figure shows, the resulting system will not deploy as a result of impacts during normal running or handling, but will deploy in collisions requiring the operation of an airbag.

5. Full Scale Impact Tests Based on ISO/CD 13232

Table 3 Specifications of opposing vehicle

Manufacturer	Honda
Model	Accord, Japan
Year	1998-201
Mass (average) (kg)	1 300
Overall length (mm)	4 635
Overall width (mm)	1 695
Overall height (mm)	1 420
Wheelbase (mm)	2 665
Engine displacement (cm ³)	1 997

Table 4 Tests and results of airbag deployment impact conditions

Collision conditions	Dummy motion	Deploy or not
To Accord front	25 km/h	No separation from MC
	30 km/h	Just before separation from MC
	35 km/h	Separated from MC
To Accord side	25 km/h	No separation from MC
	30 km/h	Just before separation from MC
	35 km/h	Separated from MC

5.1. Test Method

The airbag was evaluated on the basis of ISO/CD 13232. Comparative evaluations of motorcycles with and without an airbag were conducted using the seven impact configurations shown in Fig. 5.

A 1998-2001 Honda Accord 4-door with Japanese specifications conforming to the stipulations of ISO/CD 13232 was employed as the opposing vehicle in the impact tests (see Table 3).

To enable evaluation under fairly severe conditions, the impact speed in the tests was increased by 4%, shown in parentheses in the figure, against the speed stipulated in ISO/CD 13232.

A MATD was used as the dummy, and injury level to the head, neck, chest, abdomen and leg regions were evaluated using the injury analysis method specified in ISO/CD 13232.

5.2. Test Results

5.2.1. System deployment / non-deployment, judgment timing

The results of each impact test using motorcycles fitted with the airbag system were collected and analyzed. The airbag deployed in five of the seven impact configurations and did not deploy in two.

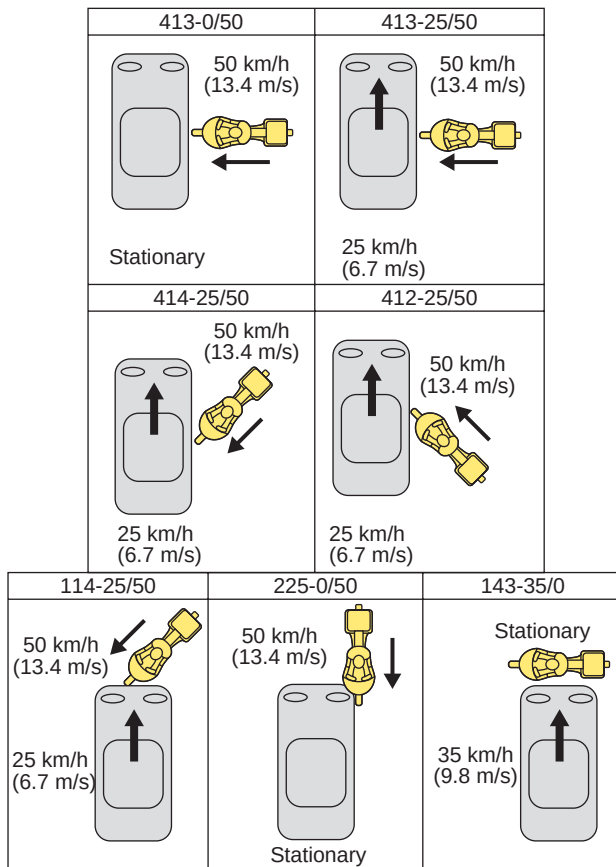


Fig. 5 Configurations of full-scale impact tests

In four impact configurations in which the airbag deployed (413-0/50, 413-25/50, 414-25/50 and 114-25/50), deployment was completed before the dummy reached the airbag. For these four impact configurations, Fig. 6 shows the time to fire, the airbag deployment time, and the time it takes the dummy to reach the airbag. To provide an example of the mode of deployment of the airbag and its effectiveness, Fig. 7 shows the situation at the start of impact ($t=0$ msec), the start of deployment of the airbag ($t=20$ msec), the completion of deployment ($t=60$ msec) and almost complete absorption of the kinetic energy of the dummy ($t=120$ msec) for configuration 413-25/50.

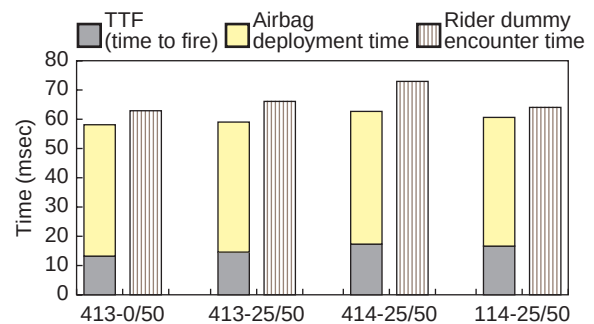


Fig. 6 Decision time of airbag deployment from full-scale impact tests

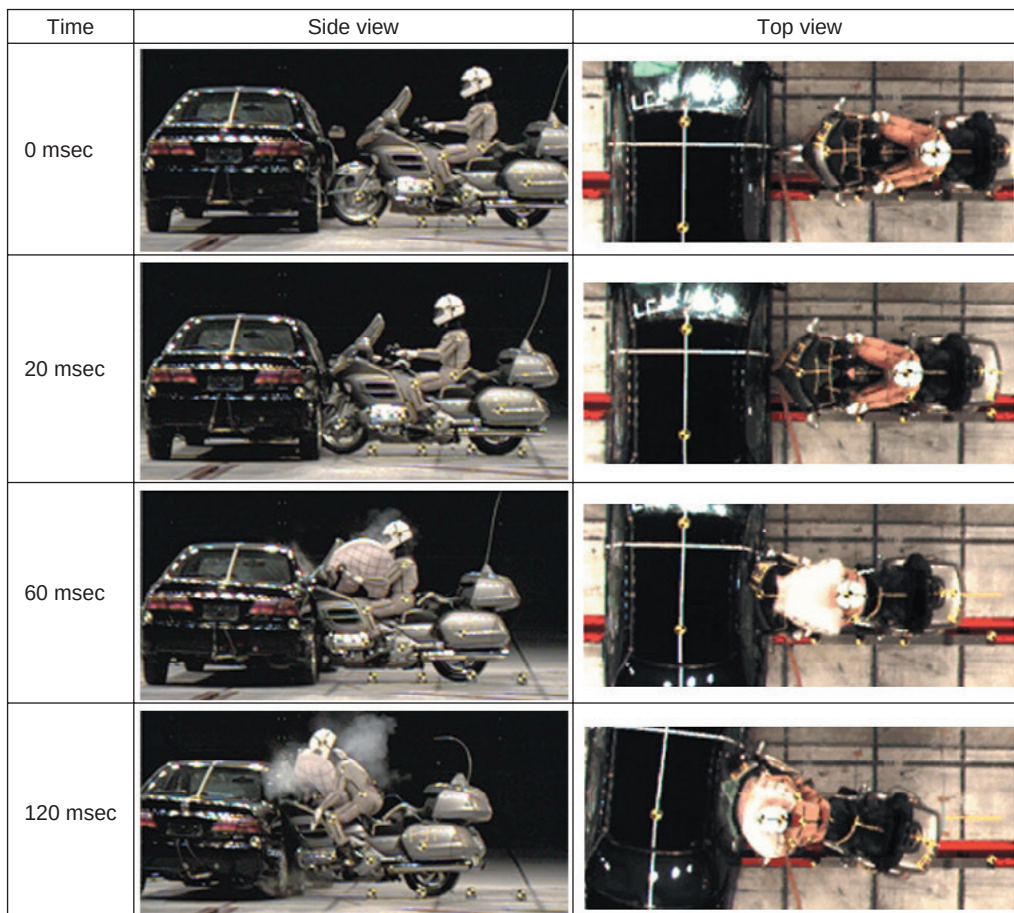


Fig. 7 Example of airbag deployment and effectiveness

In the case of configuration 225-0/50, the dummy contacted the airbag before deployment was complete, but no injury indices resulting from interference with the airbag were indicated (see the section “Results of injury analysis” below). In configurations 412-25/50 and 143-35/0, the sensor system judged that deployment was unnecessary, and therefore the airbag did not deploy. In the case of 412-25/50, although the motorcycle collided with the opposing vehicle, it did not decelerate significantly, and it was diverted along the side of the vehicle. This was not to be considered as the case of the airbag deploy because no AIS index measured (HIC 373) when the dummy head contacted the opposing vehicle. 143-35/0 is not a frontal collision, which is the objective of this airbag system, therefore, the airbag will not deploy.

5.2.2. Results of injury analysis

Changes in injury indices in the seven impact configurations, with and without an airbag, were analyzed on the basis of ISO/CD 13232. The results are shown in Table 5 in terms of changes in the Abbreviated Injury Scale (AIS) by body region, and in the Normalized Injury Cost (NIC) for the whole body. AIS=1 corresponds to minor injuries and AIS=6 to fatal injuries. NIC=0 corresponds to no injury, and NIC=1 corresponds to fatal injuries. A positive index indicates a benefit, and a negative index indicates a risk. In 412-25/50 and 143-35/0, the two configurations in which the airbag did not deploy, the airbag naturally had no effect on rider injuries.

6. Evaluation of Effectiveness in Reducing Rider Injuries by Computer Simulation

6.1. Computer Simulation

Computer simulations were employed to evaluate the effectiveness of the airbag in reducing rider injuries on the basis of ISO/CD 13232. However, ISO/CD 13232 specifies a range for evaluation up to 0.5 seconds after the motorcycle collides with the opposing vehicle (hereinafter referred to as primary impact sequence). The computer simulations employed in this research enables evaluation not only primary impact sequence but also after primary impact sequence up to the point at which the dummy makes contact with the ground (hereinafter referred to as secondary impact sequence). The degree of correlation of the computer simulation with each model and the results of impact tests was assessed on the basis of ISO/CD13232. Figures 8 to 10 show comparison data between the impact test and the computer simulation. Figure 8 shows the correlation of head HIC for primary impact sequence. Figure 9 shows the correlation of head HIC for secondary impact sequence. Figure 10 shows the correlation of chest compression for primary impact. Table 6 shows the correlation of the femurs, knees, and tibias fracture for entire impact sequence. As a result, the simulation was judged to be capable of evaluating the benefits

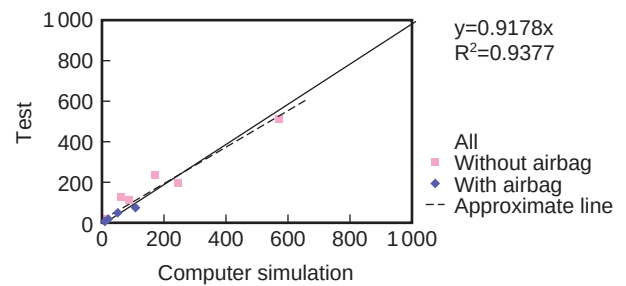


Fig. 8 Correlation of head HIC for primary impact sequence

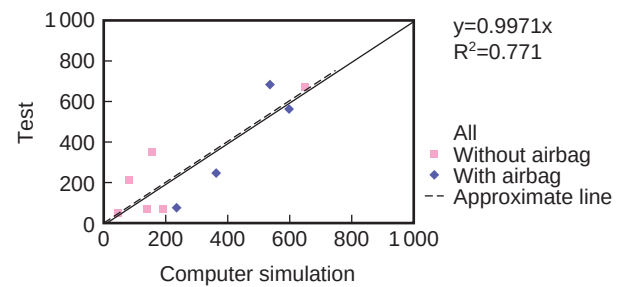


Fig. 9 Correlation of head HIC for secondary impact sequence

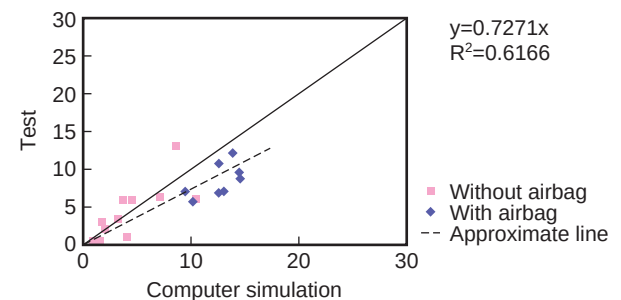


Fig. 10 Correlation of chest compression (Cmax%) for primary impact

and the risks of the airbag, in terms of rider injuries for the 200 impact configurations specified in ISO/CD 13232.

6.2. Results of Computer Simulation

In 79 of the 200 impact configurations, it was judged that the airbag would not deploy; hence, computer simulations were not conducted for these configurations. Thus, simulations were conducted with and without an airbag for 121 of the configurations, making a total of 242 cases.

The results are shown in Fig. 11. Total average benefit is 0.048 and total average risk is 0.004. The risk/benefit ratio is 0.083 and average net benefit is 0.044. These results indicate that the airbag system displays a satisfactory level of performance in reducing rider injuries.

Table 5 Airbag injury benefits and risks by impact configuration and body region

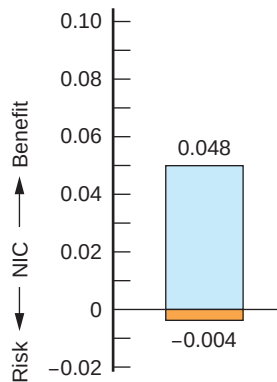
Collision configuration	AIS change					NIC change
	Head	Neck	Chest	Abdomen	Leg	
413 - 0/50	0	0	0	0	0	0
413 - 25/50	0	0	0	0	0	0
414 - 25/50	-1	0	0	0	0	-0.07
412 - 25/50	-	-	-	-	-	-
114 - 25/50	-1	0	0	0	3	0.11
225 - 0/50	0	0	0	0	3	0.16
143 - 35/0	-	-	-	-	-	-

Table 6 Correlation of leg fracture for entire impact sequence

Femurs		Full scale tests		Corrected percentage
		Fracture	No fracture	
Simulations	Fracture	0	1	96%
	No fracture	0	23	

Knees		Full scale tests		Corrected percentage
		Fracture	No fracture	
Simulations	Fracture	0	0	100%
	No fracture	0	24	

Tibias		Full scale tests		Corrected percentage
		Fracture	No fracture	
Simulations	Fracture	1	0	100%
	No fracture	0	23	

**Fig. 11** Total average benefits and risks; 200 impact configurations

7. Results of Tests under Various Conditions

In addition to the full scale impact tests in the seven ISO/CD 13232 configurations used to evaluate benefits and risks in typical collisions, tests employing other impact configurations and rider conditions were conducted to further evaluate the airbag's effectiveness.

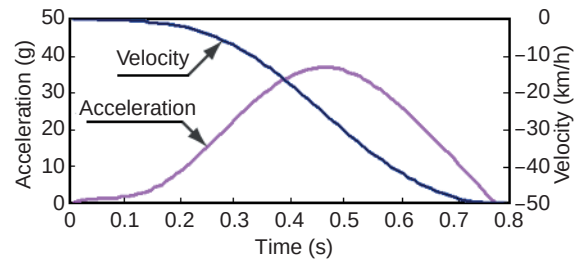
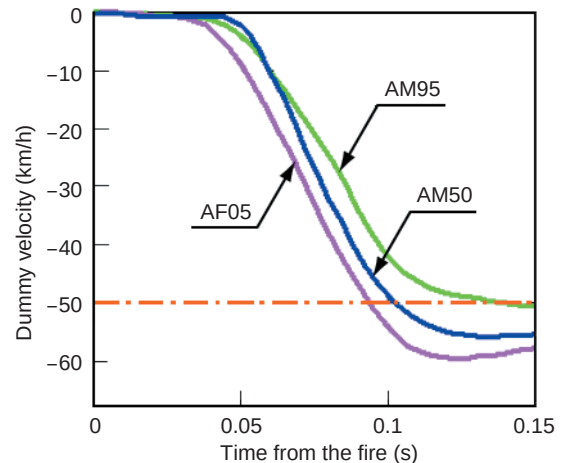
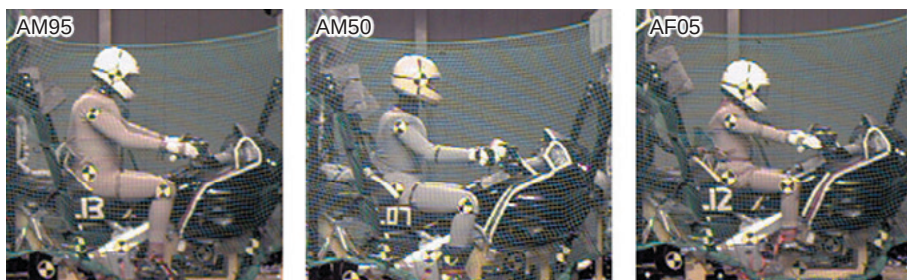
7.1. Influence of Rider Size

Sled tests were conducted with dummies of three different sizes in order to investigate the effectiveness of the system with riders of different sizes. A standard-sized dummy, AM50 percentile (H-III), a smaller-sized dummy, AF05 percentile (H-III) and a

larger-sized dummy, AM95 percentile (H-III), were employed. Injury indices for the head, neck and chest were measured and evaluated on the basis of the stipulations of FMVSS208 and related data^{(8), (9)}. The neck of the AM50 dummy was replaced with an MATD neck for measurement and evaluation based on ISO/CD 13232.

The acceleration waveform of the sled in the tests was based on the deceleration produced waveform, when a motorcycle traveling at 50 km/h collides with a stationary four-wheeled vehicle. The acceleration waveform of the sled is shown in Fig. 12. Figure 13 shows the motorcycle and the dummy when set on the sled.

The changes in the velocity of the upper half of the dummies are shown in Fig. 14. None of the three dummies were thrown forward, off the motorcycle. Figure 15 shows the absorption of the kinetic energy of the dummies by the airbag, and Table 7 shows the results of dummy injury measurements. In these tests, no injury indices in the head, neck or chest exceeding the injury criteria were recorded in any of the dummies.

**Fig. 12** Acceleration and velocity change of motorcycle in sled tests**Fig. 14** Velocity change of dummy's upper body**Fig. 13** Initial dummy posture in sled tests

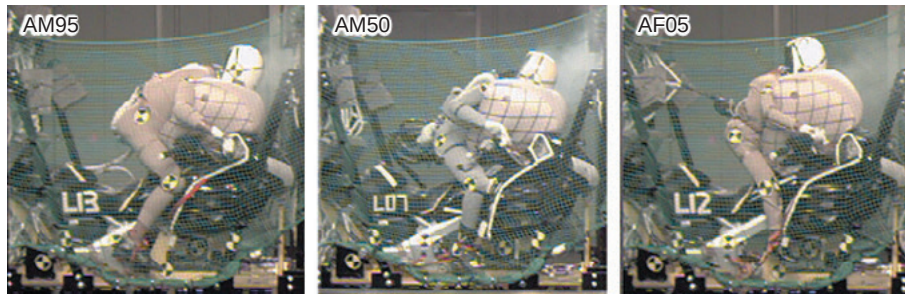


Fig. 15 Dummy posture at the moment when airbag absorbs kinetic energy

Table 7 Dummy injury indices in sled test results

Dummy size	Head HIC	Neck Nij (or Nil)	Chest D max.
AM95	52 (not over 700)	0.56 (not over 1)	32 (not over 70mm)
AM50	134 (not over 700)	2.0 (not over 4)	26 (not over 63mm)
AF05	134 (not over 700)	0.73 (not over 1)	17 (not over 52mm)

Criteria are shown in parentheses.

7.2. Effect of Airbag Deployment When Rider Is Leaning forward

We also considered the fact that motorcycle riders change their posture while riding. In particular, we want to try to mitigate any injury that could occur due to the deployment of the airbag, including when a rider is leaning forward into the airbag's deployment zone. A static deployment test confirmed that the airbag would not cause a serious injury in this case. The tests assumed that the rider was leaning forward. A standard-sized AM50 percentile (H-III) dummy and a smaller-sized AF05 (H-III) dummy were used in the tests. Injuries to the head, neck and chest were measured and evaluated on the basis of the stipulations of FMVSS208. The neck of the AM50 percentile dummy was replaced with an MATD neck for measurement and evaluation based on ISO/CD 13232.

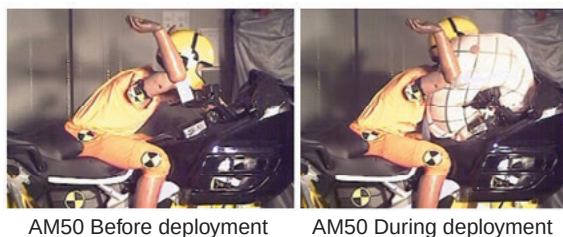


Fig. 16 Static inflation test with forward leaning AM50-dummy

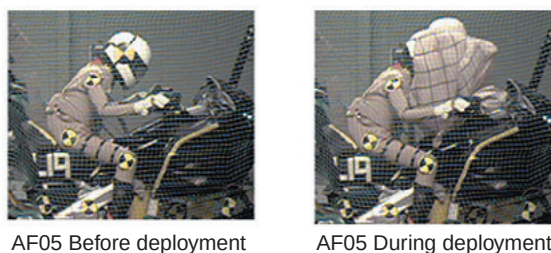


Fig. 17 Static inflation test with forward leaning AF05-dummy

The situation of the dummies before and during deployment of the airbag is shown in Figs. 16 (AM50 percentile) and 17 (AF05 percentile). In both cases, the airbag initially deployed in the region of the chest and neck, after which it contacted the head and moved the neck backwards. The results of the dummy injury measurements are shown in Table 8. In these tests, no injury indices exceeding the injury criteria were measured in either the AF05 or AM50 dummy.

7.3. Effect of Airbag on Rider in High-speed Collision with Passenger on Motorcycle

A collision test was created with the combined conditions of two riders and a higher impact speed. The focus of the test was an analysis of the results of a situation in which a passenger exerted pressure on the rider from behind, while the rider is contacting the airbag.

In the test, a Honda Accord impacted a stationary motorcycle with an airbag at 75 km/h. The opposing vehicle colliding with a stationary motorcycle is used to suppress the pitching of motorcycle body, and therefore is considered more appropriate for the purpose of the test. An MATD (AM50 percentile) was used as the rider dummy, and injuries were evaluated on the basis of ISO/CD13232. An AM95 percentile (H-III) dummy was employed as the passenger dummy to generate a greater impact with the rider dummy.

As Fig. 18 shows, during the impact test, the rider dummy was first in between the airbag and the passenger dummy. After this, the passenger dummy moved forward off the motorcycle, while the kinetic energy of the rider dummy was being absorbed by the airbag and the rider dummy remained on the motorcycle. The airbag was not damaged during this test. The results of injury measurements on the rider dummy are shown in Table 9. Injuries to the upper body were focused on, because it is in this area that the airbag will have an effect. Other than a measurement of AIS 1 in the chest, no injury index that can be represented on the AIS was measured in the region of the head, neck and chest in this test.

7.4. Under-ride Impact

In certain impact configurations, the front wheel of the motorcycle is not the first point of contact with the opposing vehicle or object. One example of this type of collision (termed "under-ride impact," below) is a collision with the platform of a truck.

Table 8 Measured dummy injury in static inflation test with forward leaning dummy

Dummy size	Head HIC	Neck Nij (or Nil)	Chest D max.
AM50	168 (not over 700)	1.55 (not over 4)	5.5 (not over 63 mm)
AF05	37 (not over 700)	0.53 (not over 1)	0.4 (not over 52 mm)

Criteria are shown in parentheses.

Under-ride impact tests were conducted to determine whether the airbag system, which judges whether to deploy, and the timing of deployment on the basis of deceleration of the front wheel system, would operate and deploy in this case.

A motorcycle with an airbag was collided with an opposing trolley with a brake applied, as shown in Fig. 19, at a speed of 50 km/h. The trolley was rigged to simulate the platform of a truck. The main specifications of the trolley are shown in Table 10. An MATD was employed as the dummy in the tests, and injury indices were measured and evaluated on the basis of ISO/CD 13232.

In the test, the timing of collision judgment by sensor system was 30 msec after the initial impact. The dummy made contact with the airbag as it was inflating, and did not collide directly with the under-ride rig. The airbag absorbed the dummy's kinetic energy. Figure 20 shows the dummy and the airbag during the test, and Table 11 shows the results of injury measurements. In this test, no injury indices were measured which could be represented on the AIS.



Fig. 20 Under-ride impact test

Table 11 Measured injury in under-ride impact test

Rider dummy	Injury by body region (AIS)			
	Head	Neck	Chest	Abdomen
MATD	0	0	0	0

8. Conclusion

A GL1800 motorcycle fitted with a prototype airbag system was evaluated in full scale impact tests and computer simulations based on ISO/CD13232. Furthermore, by other tests and conditions set independently by Honda.

The following findings were obtained:

- (1) The sensor system, using a judgment logic based on detection and calculation of deceleration in the front wheel system, was capable of appropriately judging the deployment/non-deployment of the airbag in collisions and other impacts.
- (2) As the results of the evaluation based on ISO/CD 13232, the airbag system has shown an overall benefit.
- (3) 75 km/h impact tests with two riders, tests with large and small riders, tests with the rider leaning forward, as well as under-ride impact tests, were carried out to study the effectiveness of an airbag under a variety of conditions, and no unacceptable results were generated.

Given these results, an airbag system for large touring motorcycles, like the GL1800, can be judged to be feasible. Future research will consider durability, weather resistance, reliability, marketability and productivity, looking towards the practical use of the system.

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Fig. 18 75 km/h impact test with a passenger

Table 9 Measured injury of rider dummy in 75 km/h full-scale impact test

Rider dummy	Injury by body region (AIS)			
	Head	Neck	Chest	Abdomen
MATD	0	0	1	0

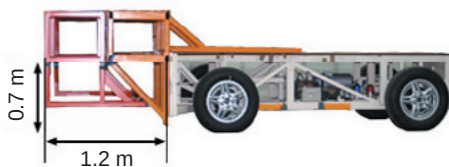


Fig. 19 Opposing trolley used in under-ride impact test

Table 10 Specifications of opposing trolley

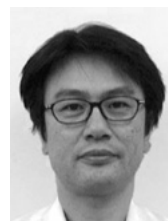
Mass	1750 kg
Overall length	4250 mm
Overall width	2080 mm
Overall height	1300 mm

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