## EXPLORATORY STUDY OF AN AIRBAG CONCEPT FOR A LARGE TOURING MOTORCYCLE

Satoshi Iijima Soichiro Hosono Atsuo Ota Takenori Yamamoto Honda R&D Co., Ltd Japan Paper Number 98-S10-O-14

## ABSTRACT

Honda began its research on motorcycle rider protection in the 1960's and since then has been active, along with other researchers in this field. One type of protection system - a motorcycle mounted airbag system has been researched in various countries since the 1970's. Recently, Honda has focused its motorcycle airbag research on one particular concept aimed at: reducing rider ejection speed; minimizing sensitivity to motorcycle impact angle, and motorcycle or opposing vehicle shapes; application to motorcycles which have a mass much larger than the rider mass; realizing a practicable airbag size and location; and consideration of both the running and impact motions of motorcycles.

Prototype devices intended to meet these objectives were refined by testing, and a prototype airbag system for a GL 1500 motorcycle was designed including special bag shape, inflator, cover and sensor system. The prototype system was evaluated using full scale impact tests and computer simulation procedures based on ISO 13232, across a range of car impact configuration, with a 50<sup>th</sup> percentile male MATD dummy. Results indicate some prototype airbag potential benefits and adverse effects. Factors not yet considered include: other sizes and positions of riders; small, medium and step-through motorcycles; other objects and opposing vehicles types; reliability and environmental exposure on motorcycles; and other factors.

## **INTRODUCTION**

Since its founding 50 years ago, Honda has been actively researching new motorcycles and other vehicles, with safety as an important consideration.

Honda began its research on motorcycle rider protection in the 1960's (Ref 1), and since then has been active, including joint work with others in this field.

Recently, Honda focused on an airbag system as one candidate for a rider protection device, and conducted a basic study on the concept of motorcycle airbags. As a

result, it was recognized that conceiving one airbag concept that would be functional for all motorcycle types would be extremely difficult. Subsequently, efforts were focused on an airbag system for a specific, large and heavy motorcycle - the GL 1500 - which was seen as an apparent airbag candidate because of its size, weight and configuration. This paper describes an exploratory study of an airbag system for one specific, large motorcycle - the GL 1500 - and in general this study is not considered to be applicable to other sizes, types or models of motorcycle.

A prototype airbag system for the GL 1500 was designed based on knowledge derived from basic studies. Research of the system components was done by means of static inflation tests, sled tests, and other preliminary tests and analysis. The sensor system aspects were considered by means of various running tests and preliminary crash tests. As a result of these basic studies, a prototype airbag system was fabricated.

As a next step a series of full scale crash tests and computer simulations was done, using the prototype airbag motorcycle and based on the full scale test and analysis procedures defined in ISO 13232. Additional full scale impact configurations were also added. Computer simulations across a wider range of motorcycle/car impacts was also done, also according to ISO 13232. This paper presents the results of these exploratory tests and simulations.

To evaluate the overall feasibility of an airbag system, many items should be studied, as described in Fig 1. The content of this paper would be only one portion of an overall feasibility study for a motorcycle airbag system for one type of motorcycle.

## **Riders**

Single Double Small Medium Large Out-of-position

### **Motorcycles**

Configuration, type Size Weight

## **Impacts**

#### **Opposing objects:**

Car types Other vehicles types Fixed objects Road (fall down) Speeds Angles Contact points

### Non-Impacts

#### Resistance to:

Road bumps, vibration Environmental exposure Maintenance/repair Use and misuse Theft Tampering Disposal

Consequences of Unintended Deployment:

Figure 1. Topics for consideration in motorcycle airbag feasibility research.

## CONCEPT OF THE PROTOTYPE AIRBAG IN HONDA'S EXPLORATORY STUDY

An examination of statistics for motorcycle fatal accidents in Japan (Ref 2) indicate that (Fig 2):



Figure 2. Data describing motorcycle fatal accidents in Japan (Ref 2)

- they are mostly (ie, about 65 percent) motorcycle frontal impacts;
- most rider impacts (ie, about 90 percent) are against objects other than the motorcycle;
- the most frequently and severely injured body region lies in the upper half of the body.

Based on this data, a typical fatal accident scenario involves: impact at the front of the motorcycle, the rider separating from the motorcycle, hitting an opposing vehicle or ground and receiving a fatal injury to the upper half of the body.

From this information, a concept involving non-ejection or energy reduction of the rider was conceived as one concept for rider protection. Subsequently, Honda has studied a motorcycle mounted airbag as one implementation of this concept.

Additional factors were also considered, including the following, based on past test experience and accident data:

 the airbag position and horizontal forces being supported by the motorcycle itself (eg, even in front-to-front impacts with passenger cars the airbag should function without the airbag needing to be in contact with the opposing vehicle);

- maintaining airbag effectiveness as much as possible during various motorcycle crash motions, especially the yaw, pitch and roll motions which tend to occur during motorcycle crashes;
- not increasing the risk of fatality in higher speed impacts.

### Test Motorcycle for Installation of the Prototype System

The GL 1500 motorcycle shown in Fig 3 was selected for this exploratory study. This motorcycle is the largest made by Honda and was selected for several reasons. In view of some of the potential technical challenges related to installation of airbags on motorcycles, selection of the GL 1500 tended to minimize these because of:

- its internal (under the seat) fuel tank, which allows an airbag module to be installed in the space in front of the rider, without affecting the fuel system;
- its upright riding position, which increases the space available in front of the rider for the airbag to inflate;
- relatively low center of gravity, large mass (370 kg with airbag system) and large inertia results in less motorcycle pitching, rolling, yawing or somersaulting during impact;
- its large full fairing may also contribute to reduced motorcycle pitching during impact.

Specifications of the GL 1500 motorcycle are given in Appendix 1.



Figure 3. Prototype airbag system installed on the GL 1500 motorcycle.

# Bag specifications and installation of the airbag on the motorcycle

The prototype airbag specifications indicated in Table 1 were set based on a series of basic tests, considering the goals of rider non-ejection, energy absorption and acceleration-reducing performance. Figures 4 and 5 illustrate the overall shape of the airbag and the internal tethers, which control bag shape.

	Table	1.
Prototype	Airbag	Specifications

Volume:	120 liter (net, inflated)	
Height x width x length:	630mm x 500mm x 615mm	
Vent holes:	2 x 50mm diameter	
Tethers: - Connecting rear and bottom sides - Connecting right and left sides	3; forms a concave "V" bag shape; see Fig 4, 5 1; to reduce bag/handlebar contact	
Bag mounting:	<ol> <li>to module box</li> <li>to motorcycle frame beneath the seat, via</li> <li>connecting belts</li> </ol>	



Figure 4. Photo showing shape of prototype airbag.



Figure 5. Schematic of airbag internal tethers.

The airbag specifications have taken into account the following considerations and test experience:

- Excessively small (or no) vent holes can result in undesirable dummy motions, such as rearward rebound or large lifting or sidewards deflection; excessively large vent holes result in less restraint and energy absorption;
- The "V" shaped planform assists in stabilizing the bag against small amounts of rider position offset or changes in motorcycle motion;
- The bag is subjected to large shear forces as the rider moves forward and over the bag. The connecting belts attached to the motorcycle beneath its seat act to resist these forces. This also allows more design freedom by not requiring the module position (ie, the main anchoring point) to be at the rearmost portion of the bag.

#### Inflator, cover and module box

Appropriate inflator characteristics were chosen mainly from static inflation tests. Figure 6 presents results of the static inflation tests. The horizontal axis shows time, and the vertical axis shows the inflated area as measured from a side view high speed camera. The results indicate that a maximum pressure of 300 kPa produced insufficient bag expansion; 350 kPa required excessive time to reach maximum expansion; and 450 kPa produced rapid and well-damped bag expansion.

Considerations were also given to the design of a module cover which would open at the beginning of airbag inflation; bag folding method; and specifications for the module box for containing the inflator and folded bag. Specifications for these are described in Table 2.



Figure 6. Time histories of inflated area (side view) as a function of maximum inflation pressure

Table 2.			
Specifications	of	Airbag	Module

Inflator:	Pyrotechic; passenger car type; 450 KPa maximum pressure; see Fig 7.
Module cover:	Thermo Plastic Elastomer (TPE) with shearing portion; passenger car type; aluminum plate hinge to allow full opening of cover; see Fig 8.
Bag folding pattern:	See Fig 9.
Module box:	Container for bag and inflator, with cover attachment; see Fig 10.
Airbag mounting:	See Fig 11.

These specifications include the following considerations and test experience factors:

- the inflation direction of the bag was desired to be forward and upward, not towards the rider;
- minimal attention was given to styling and detailed design aspects, at this exploratory stage.



Figure 7. Photo of inflator unit



Figure 8. Photo of airbag module cover hinge.



Figure 9. Folding pattern of bag.



Figure 10. Module assembly.



Figure 11. Airbag mounting on GL 1500.

### Sensor System

The sensor system needs to quickly distinguish crash conditions from normal running conditions; and to send a signal to activate the inflator. Several sensing concepts (eg, crash acceleration; bending of the front fork; crush of the frontal structure; etc) were considered and from those, use of the acceleration at the front fork near the axle seemed to be the most useful. To implement this concept, several crash tests and running tests were done, and the specifications in Table 3 were derived.

The sensor system specifications were based on the following considerations:

 Accelerations at and to the rear of the steering head can be used to distinguish "normal" and "crash" conditions, but these signals contain delays which can be too long;

Table 3.Sensor System Specifications.

Sensors:	Accelerometers; at front axle; perpendicular to front fork and front axle; see App 2, Fig 2-1.
Sensing units:	Left and right sides of front fork; signals calculated separately; earlier signal triggers the system; see App 2, Fig 2-2.
ECU:	See App 2, Fig 2-2.
Calculation method:	If sensed acceleration (rearward/downward) exceeds 9g, start "velocity change" exceeds 2.4 m/s, send trigger signal; if "velocity change" does not exceed 2.4 m/s and acceleration becomes less than 9g stop "velocity change" calculation, and reset to zero; see Figs 12, 13.



Figure 12. Acceleration and velocity change, crash test example

 two sensors near the front axle were used in the prototype system, however one sensor at the center of the front axle may be adequate for functional purposes.



Figure 13. Acceleration and velocity change, running example

Figure 14 presents the change of velocity calculated with the method described in Table 3 using signals sensed during example running conditions and crash conditions. The running conditions included bumpy road running, and running over a curb. Many of the running conditions resulted in zero velocity change, since the acceleration did not reach the level which initiates calculation of the velocity change. A velocity change of 0.6 m/s was the maximum reached in these running tests, however, further research is needed to determine whether larger values may occur in other running situations.

In contrast, velocity changes in crash conditions were usually 2.9 m/s or greater in a 20 mi/h impact to a passenger car (eg, a Corolla), and 5.7 m/s or greater in a 30 mi/h impact. Therefore a velocity change of 2.4 m/s, initiated by a 9 g acceleration excedance, was able to distinguish running conditions from crash conditions, in this exploratory stage of research. The time required to make this judgment is approximately 10 to 21 ms, based upon the data in Fig 14.



Figure 14. Velocity changes recorded in normal running and crash conditions, and judgment time required.

# FULL SCALE CRASH TEST CONDUCTED WITH THE PROTOTYPE AIRBAG SYSTEM

## **Test Methods**

Twenty full scale impact tests against passenger cars were conducted, based in general upon ISO 13232 - *Test* and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles (Ref 3). Six out of the seven full scale pairs<sup>1</sup> listed in ISO 13232 - each pair comprising a baseline motorcycle test and an airbag motorcycle test — were done, for twelve of the tests. Eight additional tests involving five other impact configurations were also done. These additional tests were for observing airbag effects considered relevant for this particular airbag concept, including the following items:

- high speed impact: 45 mi/h frontal impact of the motorcycle to the front and to the side of a stationary car;
- rider with passenger: 30 mi/h frontal impact of the motorcycle with rider and passenger to the front of a stationary car. The rider dummy was an instrumented ISO 13232 MATD 50th percentile male dummy, and the passenger dummy was an uninstrumented 50<sup>th</sup> percentile Hybrid III male dummy with sit/stand pelvis;
- Forward leaning posture: 30 mi/h frontal impact of the motorcycle to the front of a stationary car, with the dummy torso angle inclined forward 45 degrees from vertical.

Figure 15 illustrates the impact configurations used.

6 Configurations from ISO Full Scale Test Standard					
412-15/30	114-15/30	413-15/30	414-15/30	225-0/30	413-0/30
30 mph 15 mph	30 mph	30 mph 15 mph	30 mph 15 mph	30 mph A	30 mph Parked
ISO Configuration not tested, not related to airbag research	5 Configurations added for airbag feasibility research				
143-22/0	115-0/30	115-0/45	413-0/45	115-0/30	115-0/30
22 mph	30 mph A	45 mph A	45 mph 45 mph Parked	30 mph	30 mph A

Figure 15. Impact configurations used.

The car-front-to-motorcycle-side ("broadside") impact configuration of ISO 13232 was not tested in this exploratory research, since it did not seem to have a direct relation to a frontal airbag device.

The rider dummy used for all tests was an ISO 13232 Motorcyclist Anthropometric Test Device (MATD). Measurement of injury indices for the head, neck, chest, abdomen, upper legs, knees and lower legs were made in accordance with ISO 13232.

The opposing vehicle for all tests was a Toyota Corolla, in accordance with ISO 13232. However, the US Corolla model was used rather than the Japan model, because of availability, and because inclusion of side protection beams in the US model was judged to be more representative of the worldwide trend.

### **ISO Impact Tolerances and Accuracies**

Appendix 4 lists the relative and absolute tolerances in impact conditions prescribed by ISO 13232, and the conditions measured in these exploratory tests. Some excedance of some of the tolerances occurred in some of the tests, however because of the exploratory nature of these tests, these excedances were judged to be acceptable.

## **COMPUTER SIMULATION PROCEDURES**

Computer simulation models of the GL 1500 with and without the prototype airbag, the US Toyota Corolla, and the MATD dummy were formulated and calibrated in accordance with the ISO 13232 simulation procedures.

The models had the following multi body segments and finite elements:

-	GL1500	7 segments
-	Airbag	614 finite elements
-	Dummy	30 segments
-	Toyota Corolla	7 segments

The airbag sensor location, orientation and logic described previously were also modelled.

The models were implemented with software which linked the US Air Force's Articulated Total Body multi body simulation with Livermore Software's LS-DYNA3D nonlinear finite element simulation.

Laboratory tests were done of the MATD dummy, the GL1500, the airbag and the US Corolla, and calibration of the simulation against test data from 32 laboratory tests was done in terms of force-deflection and force-time characteristics.

The simulation was also calibrated and correlated with data from the nine full scale test pairs which involved the GL1500 motorcycle with and without an airbag, for the primary impact period (ie, the first 500 ms of the impact sequence), according to ISO 13232. Figure 16 shows the

correlation between the simulation and the full scale test data in terms of head maximum resultant linear acceleration. This indicates a correlation coefficient  $(r^2)$  of 0.88. Table 4 lists results for "percentage correct" injury predictions for the upper legs, knees, and lower legs, which indicated 94 percent or more agreement between simulation and test data.



Figure 16. Correlation of head maximum resultant linear acceleration.

Figure 17 compares a top view image of the simulation to the corresponding image from the full scale test. Subjectively, there was close agreement in terms of motions, between the simulations and the 18 full scale tests.

The calibrated simulation was next used to simulate the 200 motorcycle/car impact configurations representing 501 real accidents in Los Angeles and Hannover (ie, some impact configurations had multiple occurrances), according to ISO 13232, for the primary impact period, and with and without the airbag fitted to the GL1500.

The time histories of the motions and forces from these simulations were then analyzed to determine dummy injury indices, according to ISO 13232.

## INJURY ANALYSIS METHODS

The injury analysis methods used to analyze both the full scale test data and computer simulation data were those specified in ISO 13232. This includes calculation of injury assessment values and injury indices for the head, neck chest, abdomen, upper legs, knees and lower legs; and combining the information for all body regions to calculate

# Table 4.Leg Injury Correlation

Femurs		Full Sca	Percent correct	
		Fracture	No Fracture	94%
Simulations	Fracture	0	2	
	No Fracture	0	34	
<u>Knees</u>		Full Sca	le Tests	
		Fracture	No Fracture	97%
Simulations	Fracture	0	0	
	No Fracture	1	35	
<u>Tibias</u>		Full Sca	le Tests	
		Fracture	No Fracture	94%
Simulations	Fracture	0	2	
	No Fracture	0	34	

the Normalized Injury Cost (NIC) for each test (NIC = 0.0 corresponding to no injuries, and NIC = 1.0 corresponding to a fatal injury).

Example injury assessment values (IAV) and corresponding injury index (II) values, excerpted from ISO 13232, are listed in Table 5, for general reference.<sup>1</sup>

Two additional injury analysis procedures were used in addition to those of ISO 13232: a preliminary neck injury assessment; and additional injury risk/benefit calculations.

**Preliminary Neck Injury Assessment** - ISO 13232 includes a method to calculate Neck Injury Indices (NII), but includes no specific criteria or injury probability curves which relate the NII values to probability of different severities of neck injury, as ISO 13232 provides for other body regions.

<sup>1</sup> The IAV and II relationships defined in ISO 13232 are in many cases continuous, multivariable functions. The examples listed here are for approximate, example reference and are not definitive.



a) Computer Simulaton



b) Full Scale Test

Figure 17. Example comparison of side view of simulation with full scale test, impact configuration 412-15/30, airbag.

The rationale for ISO 13232 (Part 5, Clause H.3.8) states in a general way that:

"[NII] values near or above 1.0 are interpreted as likely neck fracture or dislocation; with significant likelihood of spinal cord damage, which at the C1/A0 location, has a fatal propensity."

It has been reported elsewhere (eg, Ref 6) that more research is needed: to improve the biofidelity of the dummy neck used in motorcycle impact research; and to clarify the probabilities of various types and severities of

Table 5.
Example Injury Assessment Variable (IAV) Values
and Corresponding Injury Index Values (II)
from ISO 13232 <sup>1</sup>

Body Region /IAV	Example IAV Value	Corresponding II Value
Head G (= normalized resultant of a, and $\alpha_r$ )	0.85 (= 140g with simultaneous peak of 15.8 Kr/s <sup>2</sup> )	P-AIS2
Neck Shear Tension Compression Flexion Exension Torsion	5.0 kN, or 5.0 kN, or 4.0 kN, or 300 Nm, or 90 Nm, or 40 Nm	NII = 1.0 (P-AIS6 assumed)
Chest Compression Velocity- compression	24%, or 0.2 m/s (with V>3 m/s)	P-AIS1 P-AIS1
Abdominal Penetration	35 mm	P-AIS1
Femur Fracture	Non displaced	P-AIS3
Knee Dislocation	Partial	P-AIS2
Tibia Fracture	Non displaced	P-AIS2

neck injury, given measurements of the forces and moments acting upon a more biofidelic dummy neck.

In the interest of proceeding with exploratory airbag research, however, a conservative or worst case assumption regarding neck injury probability was made. Given the criticality of neck injury and the aforementioned uncertainties, it was assumed for purposes of this research that NII values greater than 1.0 would correspond to "certain, fatal neck injury." This assumption was then included in the injury analysis for both the full scale tests and the computer simulations.

Additional Injury Risk/Benefit Calculations -ISO 13232 describes a method which quantifies the percentages of the 200 impact configurations in which a given device is "beneficial", and in which a given device is "harmful," based on test and simulation results.

An amendment to ISO 13232 has been proposed (Ref 4) which would also calculate the total amount of benefit and harm (or "risk"), in addition to the percentages

of cases which are beneficial and harmful. For purposes of assessing the amount of airbag benefit and harm in this exploratory study, this proposed amendment was considered to be useful. However, a slight modification of the equations in the proposed amendment, described in Appendix 3, is considered to better describe both the amount and the percentage of cases in which a device is beneficial or harmful. These modified equations were used in the analysis of the test and simulation data.

With regard to risk and benefit criteria, these have not been established or discussed for motor vehicles in general. However, for comparison purposes, the equations of Appendix 2 were applied to example car airbag data for the United States (Ref 5), and the results are summarized in Table 6.

Table 6.
Example Risk and Benefit Data for US Car Airbags,
Fatals Only (Based on Ref 5)

0	Live		
Category	Saved (Benefit)	Lost (Risk)	(%)
All	<b>2920</b> <sup>1</sup>	94 <sup>2</sup>	3
Drivers	2536	36	1
Adult Passengers	384	4	1
Passengers	<b>38</b> 4 <sup>1</sup>	45 <sup>2</sup>	12

<u>Notes</u>

1 Assumes zero child lives saved by airbags.

2 Excluding children in rear facing child safety seats.

The US car airbag data indicate that the estimated airbag risk-to-benefit ratio for drivers and for adult front passengers is about 1 percent. Airbag "benefit" data for children are not available; however if a worst case assumption is made that no child lives are saved by airbags, the resulting risk-to-benefit ratio for all front passengers - including children - is 12 percent (and less than this if there are some child lives saved by airbags).

So, it is observed that for car airbags, risk- to -benefit ratios for adults are about 1 percent, and for all front occupants are about 12 percent or less. It is also observed that designs and regulations for US car airbags are being modified in order to reduce the injury risks for front occupants (ie, in order to reduce the 12 percent statistic). From this background it was considered on a preliminary basis that airbag risk-to-benefit ratios of 12 percent or more are relatively large and undesirable, and that ratios of 1 percent describe performance levels which currently occur for normal sized adult car occupants.



Figure 18. Airbag timing data from full scale tests.

# RESULTS OF THE FULL SCALE TESTS OF THE PROTOTYPE AIRBAG SYSTEM

#### System Functionality

Figure 18 presents the time required for each of the important time periods of airbag functioning: the sensing time, the deployment time and the dummy time-to-contact, for the eleven full scale tests with airbags.

The sensing time is measured from first motorcycle/opposing vehicle contact until the trigger signal occurs. The deployment time is measured from the trigger signal until complete inflation. The dummy's time-tocontact is measured from first motorcycle/opposing vehicle contact until the dummy contacts the airbag. Time data were based on recordings in the ECU and on high speed film analysis.

Note that in the offset frontal impact configuration 225-0/30, although the acceleration and velocity change did not reach the criteria for airbag deployment, the airbag system was deployed. This was considered to be a case of "unintended deployment," probably caused by electromagnetic interference (EMI), for which there was no special electrical shielding provided in the prototype system.

For the 10 intended deployment tests, the dummy contacted the fully inflated airbag 2 to 26 ms after full inflation (average of 13 ms), except in the dummy leaning forward case. Sensing and inflation times were 8 to 14 ms and 34 to 46 ms respectively. So, overall, the system was considered to have functioned as intended with regard to timing for this series of tests.

In order to further evaluate the timing performance of the prototype system, further tests with conditions which are closer to "borderline" inflation conditions would be needed, such as crashes at lower speeds, or with lighter weight or less stiff opposing vehicles. Further study is needed with these and other conditions to determine whether the rider may contact the bag before full inflation, whether there are potential harmful effects and possible design changes to reduce or eliminate these.

## **Preliminary Results of Injury Evaluation**

The effects of airbag deployment on injuries are summarized hereafter, based on dummy measurements from the full scale test pairs (with and without airbags), the ISO 13232 injury evaluation methods and the injury risk/benefit calculations of Appendix 3.

**Results for each test pair and body region** - Figure 19 presents the injury risks and benefits for each test pair, in terms of the change in AIS for each body region and NIC (across all body regions). The shaded portions indicate results for the period prior to 500 ms - the primary impact sequence - during which the main motorcycle, dummy and opposing vehicle interactions occur. The unshaded portions indicate results for the entire impact sequence, which includes dummy/ground contact and the dummy coming to rest.

Figure 19 indicates that:

- the main airbag effects (both risks and benefits) are to the head and neck, and are related to ground contact (ie, they do not occur during primary impact).
- in terms of NIC, the airbag is beneficial in 4 cases, harmful in 2 cases and has little or no effect in 3 cases.

Photographs of example airbag benefit and risk cases are shown in Figs 20 and 21, respectively.

The airbag benefit case of Figure 20 is for the high speed side of car impact (impact configuration 413-0/45). With the baseline motorcycle, the dummy's helmet contacts the car roof resulting in a fatal neck injury, whereas with the airbag motorcycle, dummy energy absorption occurs, and there is no helmet contact to the car roof. The only injury is an AIS 1 head injury on ground contact.



Figure 19. Airbag injury risks and benefits, by impact configuration and body region.

The airbag risk case of Fig 21 is for the angled car side impact (impact configuration 414-15/30). With the baseline motorcycle, the dummy is ejected and somersaults forward, contacting the ground with feet and pelvis (resulting in AIS 1 head and chest injuries for the entire impact sequence); whereas with the airbag motorcycle, dummy energy is absorbed, the dummy tends to stay on or near the motorcycle, and there is a fatal neck injury on ground contact as the motorcycle and dummy fall sidewards.



a) Baseline



b) Airbag



<u>Results for each body region, all test pairs</u> - Figure 22 shows the benefit and risk by body region in terms of average change in AIS, across all impact configurations and for the entire impact sequence.

The main airbag effects - both benefits and risks - are to the head and neck. For the head and for these impact configurations, the injury benefits are much larger than the injury risks; whereas for the neck, the injury risks are relatively large in comparison to the injury benefits.



a) Baseline





## Figure 21. Airbag risk case (414-15/30)

<u>Total average benefit and risk, all test pairs</u> -Figure 23 shows the total average injury benefit and risk in terms of average change in NIC across all test pairs, and accounting for frequency of occurrence of these impact configurations in accidents, according to Appendix 3.

The data - which are applicable to the subject motorcycle, airbag prototype, opposing vehicle and this set of impact configurations - indicate that the injury benefits are greater than the injury risks; but that the risks are substantial, with a risk-to-benefit ratio of 25 percent, in terms of Normalized Injury Cost. This is substantially more than the risk-to-benefit ratio of 1 percent for car airbags, noted previously. **<u>Higher impact speed</u>** - Four of the previously described tests were for 45 mi/h motorcycle impact speeds to the front and side of a stationary car, in order to assess airbag effects at higher impact speeds.



Figure 22. Airbag injury risks and benefits by body region, all test pairs, entire impact sequence.



Figure 23. Total average benefits and risks, all tests

## **Effects of Other Test Variables**

The functioning of the prototype airbag system was observed to be satisfactory in these 45 mi/h impacts, including the timing sequence. Although some increase in dummy/airbag forces were observed at higher speeds, these increases seemed to be limited by two other phenomena: the large motorcycle pitching motion in the impact to the front of the car; and the rupture of the prototype airbag in the impact to the side of the car.

In the car front impact, as illustrated in Figure 24, a complete forward pitchover of the motorcycle occurred during which the dummy slid over the top of the airbag, which may have limited the force from the airbag. The maximum bag internal pressure was  $0.22 \text{ kg/cm}^2$ , which is relatively low. Although head and neck forces were greater than those at 30 mi/h, the maximum chest compression was less than that at 30 mi/h.



Figure 24. 45 mi/h impact tests, front of stationary car.

In the car side impact, as illustrated in Fig 20, a large amount of motorcycle pitching did not occur, due to the motorcycle fairing-to-car contact which was located well above the motorcycle center of gravity. Rupture of the bag occurred along the seam line in the 45 mi/h test, as shown in Fig 25. This may have acted to limit the amount of dummy/airbag force. The maximum bag internal pressure was  $0.35 \text{ kg/cm}^2$ .

**Forward leaning posture** - An impact to the front of a stationary car (impact configuration 115-0/30) with the dummy leaned 45 degrees forward (Fig 26) was conducted with only the airbag motorcycle, in order to investigate airbag-to-dummy contact effects in this riding position. When compared to the normal riding position test, the test



Figure 25. Photos of bag rupture which occurred during 45 mi/h impact to side of stationary car.



a) Forward leaning dummy



b) Normal position dummy

Figure 26. Impact test with forward leaning dummy.

data indicated no significant chest injury potential. The maximum bag internal pressure was 0.40 kg/cm<sup>2</sup>. Dummy neck extension and moment increased but was well below the assumed fatal level. These and the other neck injury results should be further evaluated if and when further biomechanics research clarifies neck injury probability relationships.

With Rider and Passenger - This impact to the front of a stationary car (impact configuration 115-0/30), was also conducted with only the airbag motorcycle, in order to assess the effects of rider dummy/airbag contact forces when a passenger dummy was seated behind the rider dummy.

As illustrated in Fig 27, during the primary impact the rider dummy was caught between the airbag and the passenger dummy, resulting in a small, non injurious increase in the rider dummy chest compression. The maximum internal pressure of the bag was  $0.31 \text{ kg/cm}^2$ .



Figure 27. Impact test with rider and passenger.

### **COMPUTER SIMULATION RESULTS**

Figure 28 presents the results from the calibrated computer simulations of 200 motorcycle/car impact configurations (ie, 200 pairs, with and without airbag) taking into account frequency of occurrence in terms of the "average change in AIS", due to the airbag, for five body regions (and for the primary impact period only). This indicates: relatively small injury benefits for the head and legs; substantial benefit for the neck; but also considerable injury risks for the neck and for the legs.

Further examination of the detailed simulation results indicated that the neck injury risks in many cases tended to be associated with neck hyper extension or hyper



Figure 28. Average positive and negative changes in AIS, due to airbags, by body region, 200 impact configurations, primary impact period.

torsion, caused by contact with the airbag; and that the leg injury risks were associated with some increase in leg flail and associated impacts, when the upper body was restrained.

Figure 29 presents the overall average positive and negative changes (ie, injury benefits and risks) in terms of Normalized Injury Cost for the 200 simulations, taking into account frequency of occurrence, for the primary impact period. This indicates an injury benefit during primary impact, but also a considerable injury risk, with an injury risk-to-benefit ratio of 16 percent.

Figures 28 and 29 do not apply to the entire impact sequence, where, in the full scale tests, most of the airbag injury benefits and risks occurred. Based on the full scale test results, it would be expected that the simulation results for the entire impact sequence would be substantially different from those of Figs 28 and 29. Extending the simulation to cover the entire impact sequence would involve calibrating the simulation against the full scale data for this 3 second period, which would involve a relatively complex and substantial effort.



Figure 29. Average positive and negative changes in NIC, due to airbags, 200 impact configurations, primary impact period.

### CONCLUSIONS AND RECOMMENDATIONS

A series of 20 exploratory full scale car impact tests and 400 calibrated computer simulations of car impacts were conducted to evaluate a prototype airbag system for a GL 1500 motorcycle.

The findings were that:

- In 10 out of the 11 tests with airbags, each airbag component functioned mechanically as expected (in one test there was an unintended deployment);
- Airbag deployment resulted in:
  - Decreased injuries (ie, decreased Normalized Injury Cost) in four out of nine test pairs (comparing motorcycles with and without airbags);
  - Increased injuries in two out of nine test pairs;
  - Little or no injury change in three out of nine tests pairs.
- Most of the changes in injury due to the airbag occurred at dummy/ground contact rather than during primary impact, as a result of changes in dummy motion with the airbag;
- Some uncertainty exists in the results related to neck injury probability, due to the current state of biomechanical knowledge;

- In the limited set of tests to examine particular airbag effects:
  - a forward leaning dummy posture resulted in increased neck forces during airbag contact but no change in injuries, compared to an upright dummy posture;
  - addition of a passenger resulted in increased chest deflection during airbag contact but no change in rider dummy injuries;
  - higher speed impacts resulted in increased chest compression but no change in chest injuries with the airbag, compared to lower speeds.
- Relatively large injury risk-to-benefit ratios were observed with the prototype airbag in comparison to car airbag risk-to-benefit ratios of 1 to 3 percent in accident data, ie:
  - a prototype airbag risk-to-benefit ratio of 25 percent in the nine test pairs;
  - a prototype airbag risk-to-benefit ratio of 16 percent in the 200 simulation pairs, for the primary impact period only.

In the future more research is needed to clarify:

- Evaluation methods, especially neck injury assessment and also a larger sample of ground contact injuries by means of computer simulation;
- Further study of impacts in which the airbag was found to be harmful, in order to identify possible remedies;
- Future study of many other crash and non-crash situations, and airbag injury benefits and risks in those situations;
- Exploration of the applicability of airbags to other sizes and types of motorcycles.

It is intended to continue to study these topics, with the goal of improving motorcycle rider passive safety.

## REFERENCES

 Inoue, T, Miura, K, et al, "Experimental Collision Test on Motorcycles with Passenger Cars," Paper No. 15 of the Safety Research Tour in the USA from the Viewpoint of Vehicle Dynamics, Society of Automotive Engineers of Japan, October 1969.

- 2. Anon, <u>Traffic Accident Data</u>, <u>1996</u>, Institute for Traffic Accident Research and Data Analysis, Japan, 1998.
- 3. Anon, International Standard ISO 13232:1996(E), Motorcycles - Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles. Parts 1 to 8, International Standards Organization, Geneva, December 1996.
- Kebschull, S, Zellner, J, Van Auken, M, "Proposed Amendment to ISO 13232, Part 5, 5.10.4, Risk/benefit Calculations," ISO/TC22/SC22/WG22 N236, May 1997.
- Anon, <u>Special Crash Investigation Report on Airbags</u>, National Center for Statistics and Analysis, National Highway Traffic Safety Administration, US Department of Transportation, Washington, DC, March 1998.
- Newman, J, Withnall, C, Gibson, T, Rogers, N, Zellner, J, "Performance Specifications for the Neck of a Motorcyclist Anthropometric Test Dummy," Fifteenth International Technical Conference on the Enhanced Safety of Vehicles, Melbourne, May 1996.

## **APPENDIX 1 - VEHICLE SPECIFICATIONS**

Table 1-1.							
Specifications of Test Motorcycle							

Manufacturer: Model: Vear:	Honda GL1500 Interstate
Weight (empty, as tested, no	1994-1990
airbag)	376 kg (average)
Weight (empty, as tested with	
airbag)	376 kg (average)
Length, overall:	2615 mm
Width, overall:	955 mm
Height, overall:	1495 mm
Wheelbase:	1690 mm
General size, weight:	Large, heavy
Туре	Touring

Table 1-2.Specifications of Opposing Vehicle

Manufacturer:	Toyota
Model:	Corrola, US
Year:	1989-1991
Weight (empty, as tested):	1100 kg (average)
Length, overall:	4200 mm
Width, overall:	1660 mm
Height, overall:	1360 mm
Wheelbase:	2430 mm
Type:	Sedan (Saloon)

## **APPENDIX 2 - AIRBAG SENSOR SPECIFICATIONS**





Table 2-1.Sensor Specifications					
Filter:	Low pass (243 Hz)				
Туре:	Piezo resistive				
Range:	5884 m/s <sup>2</sup>				
Excitation:	5v DC				
Current:	< 0.5 mA (peak)				

2276



Figure 2-2. Schematic of sensor units and ECU.

## **APPENDIX 3 - RISK/BENEFIT CALCULATIONS**

For purposes of this paper, the following definitions, adapted from Ref 4, were used:

benefit<sub>j</sub> = average decrease = 
$$\frac{1}{N} \sum_{\ell=1}^{N_{ben}} (-\Delta x_{\ell, j} * FO_{\ell})$$
  
in injury index j

risk<sub>j</sub> = average increase = 
$$\frac{1}{N} \sum_{k=1}^{N_{risk}} (-\Delta x_{k, j} * FO_k)$$
  
in injury index j  
(a negative value  
which indicates  
an increase in the  
average injury value)

where:

- N<sub>ben</sub> = Number of configurations in which the protective device was beneficial (ie, resulted in a decrease in the injury index value) for a given injury index
- $N_{risk} =$  Number of configurations in which the protective device was harmful (ie, resulted in an increase in the injury index value) for a given injury index
- $\Delta x =$  Change in injury index value (protective device baseline)

- $\ell =$  Subscript for each impact configuration in which there was a decrease in the injury index value
- k = Subscript for each impact configuration in which there was an increase in the injury index value
- N = Total number of accidents (= 501 for ISO 13232, Part 2, Table B.1)
- j = Subscript for each injury index
- FO = Frequency of occurrence of a given impact configuration in accidents, based on ISO 13232, Part 2, Table B.1

Note that the injury indices analyzed in this paper include the AIS values for each body region; and the Normalized Injury Cost (NIC), which includes all the analyzed body regions and injury types.

In comparison with Ref 4, the foregoing formulation has the advantages of: being in the same units as the respective injury index; not being divided by the sum of the baseline injuries, which in some cases is zero; and quantifying the <u>average</u> change (rather than just the total change) of the injury index across all of the accidents.

## **APPENDIX 4 - ISO 13232 TOLERANCES AND TEST ACCURACIES**

Impact	Absolute Tolerances					Relative Tolerances					
Configurations (Test Pair) <sup>1)</sup>	RHA <sup>2)</sup> 3	OVS 5	MCS 5	MCRA 5	CP varies <sup>3)</sup>	DP 3 <sup>4)</sup>	RHA 3	OVS 5	MCS 5	MCRA 5	CP varies
412-15/30 114-15/30 413-15/30 414-15/30 115-0/30 115-0/45 <sup>6)</sup> 225-0/30 413-0/30 413-0/45 115-0/30 fwd lean 115-0/30 passenger				X <sup>5)</sup>	XX XX X X	X X		X	X	Х	x x x
Notes		dofinad in	150 1222	L	L		<u> </u>	L	L		L

1) Impact configuration codes as defined in ISO 13232-1.

2) RHA: Relative heading angle, degrees.

OVS: Opposing vehicle speed, percent.

Motorcycle speed, percent. MCS:

MCRA: Motorcycle roll angle, degrees.

CP: Contact point., cm

DP: Dummy position, pre-test and pre-impact, cm.

3) Tolerance varies, depending on impact configuration, generally between 3 and 15 cm.

Tolerance is taken to be 3 cm, according to proposed amendment to ISO 13232, per ISO/TC22/SC22/WG22 N207 and N242. 4)

5) Х One test did not meet criterion. :

XX : Both tests did not meet criterion.

Could not measure roll angle in one test. 6)