

FACTORS AND STATUS OF MOTORCYCLE AIRBAG FEASIBILITY RESEARCH

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ABSTRACT

A review, analysis and enumeration are presented of factors relevant to motorcycle airbag feasibility research. This includes: an update of the status of related research in the motorcycle airbag feasibility field; relevant experience and factors from the car airbag field; additional unique factors and considerations for motorcycles; and the potential need to address motorcyclist out-of-position riding; other sizes of riders; motorcycle seating layout variation; resistance to and consequences of unintended deployment on a motorcyclist; neck injury criteria and dummy neck biofidelity; injury risk-benefit considerations; environmental exposure on motorcycles; and discussion of feasibility definition and factors. Also discussed are the use of component tests, sled tests, full scale impact tests and computer simulation as evaluation tools; and the relationship of such airbag factors to the existing International Standard ISO 13232, which currently primarily addresses test and analysis procedures for research evaluation of fixed devices fitted to motorcycles intended to protect the rider. An enumeration of related references and potentially related car standards are provided.

INTRODUCTION

Among the concepts that have been considered that could potentially reduce injuries to motorcycle riders in accidents is the motorcycle-mounted airbag. Whilst exploratory work in this area has occurred during the past 30 years, the feasibility (including the non-injuriousness) of motorcycle airbags has not yet been established. Such feasibility of airbags is being actively researched by the motorcycle industry, in order to seek ways to reduce rider injuries in collisions, at the same time avoiding addition of any device that could be harmful.

Airbag application to passenger cars and light trucks is growing, owing to extensive research, development and funding of this area over the last 40 years. The general success of car airbags is also related to the larger, enclosed nature of such passenger vehicles and to both customer and governmental interest in them.

Nevertheless, car airbags involve vastly different human, vehicle and environmental factors than those prevalent in motorcycles. In addition, the way in which car airbags evolved resulted in developing many evaluation tools "after-the-fact," rather than prospectively. This resulted in widespread unintended consequences of airbags, including airbag-induced injuries and fatalities, and some amount of government-mandated "experiments with the public," which is undesirable.

Overall, it seems desirable to learn in a positive way from the car airbag experience, in evaluating the potential benefits and risks of motorcycle airbags. In part, this should involve reaching a consensus on the testing and analysis methods to be used for the research and evaluation of airbag concepts. This should enable a common understanding to be reached of the potential benefits and risks of such protective devices, before they are judged to be "feasible."

MOTORCYCLE AIRBAG RESEARCH STATUS

Motorcycle airbag research began in the 1970's with the exploratory work of Bothwell (Bothwell and Peterson, 1973). Table 1 lists the main exploratory studies up through 1998. A review of these indicates that very little objective data had been published prior to 1990 and most of this is found in the exploratory work of Bothwell (for NHTSA) and Chinn and Finnis (of TRL). Almost none of this early work addressed out-of-position riders, unintended deployment, or effects on neck or chest

injuries, although these topics had been of interest in the car airbag field.

These early efforts were also characterized by a variety of motorcycle airbag “concepts,” and a relatively limited, narrow range of test conditions and evaluation methods were borrowed from the car field, as described by Zellner et al (1994). The airbag concepts included the concepts of restraint (per TRL), trajectory control (per Sporner) and energy absorption (as suggested by the Bothwell work). Subsequent research has indicated that a combination of these concepts is needed, for motorcycle airbags.

Table 1.
Motorcycle Airbag Exploratory Studies

Researcher	Date
Bothwell and Peterson	1973
Bothwell	1975
Bothwell	1976
Yamamoto	1980
Peterson, Bothwell and Knight	1981
Danner, Langweider and Sporner	1985
Chinn, Donne and Hopes	1985
Sporner, Langweider and Poulake	1987
Watson	1987
Sporner, Langweider and Poulake	1989
Watson and Donne	1989
Finnis	1990
Ouelett	1990
Happian-Smith and Chinn	1990
Sporner, Langweider and Poulake	1990
Rogers	1991
Zellner, Newman and Rogers	1994
Ramet et al	1994
Chinn et al	1996
Iijima et al	1998

In addition to a variety of airbag concepts and limitations in evaluation methodology, the early work indicated various airbag related problems in early prototypes. These included: dummy rebound from the airbag (Bothwell, 1973); the relatively large size required to protect the dummy, eg, 150 l or larger (Bothwell, 1973); trigger reliability problems (Sporner, 1987); unintended deployment (Watson, 1989); mounting location, support and critical timing issues (Finnis, 1990); the need for differently configured airbags for different motorcycles as related to motorcycle size (Finnis, 1990); front wheel stiffness effects (Happian-Smith, 1990); motorcycle pitch effects (Bothwell, 1975 and Happian-Smith,

1990); costs in relation to vehicle purchase cost (Sporner, 1987); and the observation that prototype airbags had not yet been found to be especially effective (Ouellet, 1990).

Beginning in 1990, the International Motorcycle Manufacturers Association (IMMA) began long term research into motorcycle airbag feasibility (Rogers, 1991). Phase 1 research involved improved evaluation methodologies (some of which were later standardized in International Standard ISO 13232 (1996)); 19 sled tests indicating the importance of neck/airbag interaction in rider forward-leaning riding positions; 750 computer simulations with a 84 l airbag that indicated increased potential for neck injuries, and increased head and chest injuries in some impact configurations.

IMMA Phase 2 research described by Zellner et al (1994) included forward-leaning out-of-position cadaver tests (Ramet et al, 1994) and dummy tests, which indicated strong potential for neck fracture/dislocation when a 155 l car airbag was deployed vertically at the forward end of a motorcycle fuel tank; methodology improvements including an improved motorcyclist dummy and injury indices; sensor feasibility and functional requirements; initial optimization of 5 different airbag concepts by means of computer simulations in 163 impact configurations; and initial validations tests with a prototype of one airbag concept.

The Phase 2 test results indicated some beneficial effects in 90-degree impacts to the side of a stationary car, but potentially injurious neck forces. In addition, impacts to a moving car caused the motorcycle and airbag to yaw and the helmet to slide off the ellipsoidal shaped airbag, in one case causing the helmet to strike the car in a lower, more direct manner. It was recommended that further research be directed toward improving the dummy neck and other injury assessment methodologies, and re-evaluating various airbag concepts using improved evaluation methods.

Chinn et al (1996) describe a purpose-built airbag for a large touring motorcycle, based on a preliminary design and tuning via computer simulation; prototype fabrication; static deployment tests; sled tests; and full scale impact tests using some but not all of the procedures in ISO DIS (at that time) 13232. Results indicate some beneficial effects on head injury potential during the primary impact period (up to 500 ms), but injury potential during

ground contact phase was not analyzed. The “restraint” concept airbag, in combination with fairing and knee restraints, was reported to absorb most of the dummy kinetic energy during the primary impact period. However, it is not clear to what extent the instrumentation cables trailing from the rear of the dummy might have influenced these results. The study used only a portion of the ISO methods, and unfortunately did not calibrate the computer simulation according to the ISO methods, or apply the simulation to evaluate the injury risks and benefits across the 200 impacts defined in ISO DIS 13232. Preliminary measurements of road roughness accelerations were used to infer that false triggering due to road disturbances would not occur, but an actual trigger was not developed or tested to verify this.

Iijima et al (1998) applied the full set of ISO 13232 (1996) procedures, plus several other impact configurations, to an exploratory study of an airbag concept for a large touring motorcycle. The goals of this prototype system were to reduce rider ejection speed; minimize sensitivity to motorcycle impact angle and opposing vehicle shape by use of an internally tethered, winged, concave, V-shaped airbag; implementation of a prototype triggering device; and focusing on a motorcycle which had an upright riding position, a fuel tank under the seat and a mass much larger than the rider mass.

The results of Iijima et al indicated: one unintended deployment among 11 airbag dynamic tests; decreased injuries in 4 out of 9 test pairs (comparing motorcycles with and without airbags); increased injuries in 2 out of 9 test pairs, due to changes in dummy attitude at ground contact (ie, due to somersaulting over the airbag); little or no change in 3 out of 9 test pairs; and a relatively large injury risk-benefit ratio of 25 percent in the tests (versus 3 percent risk-benefit ratio in car airbag accidents). Calibrated computer simulations across the 200 impact configurations specified in ISO 13232 indicated 16 percent risk-benefit ratio, for the primary impact period only. It was recommended that future research consider improved evaluation methods, especially for the neck, and a means to evaluate ground contact injuries by computer simulation; further study of harmful effects, in order to identify possible remedies; further study of many other crash and non-crash situations and the related airbag risks and benefits; and exploration of the applicability of airbags to other sizes and types of motorcycles.

More recently, as part of the Japan Advanced Safety Vehicle demonstration project, Honda has described a prototype airbag for a large touring motorcycle, apparently similar to that described by Iijima et al (1998); and Yamaha has described a prototype airbag for a scooter. Details of the prototypes and any testing or evaluations were not available as of January 2001.

RELATED FACTORS AND EXPERIENCE FROM THE CAR AIRBAG FIELD

A summary of car airbag technical and regulatory development is provided in various references, including Chan (2000) and NHTSA (1997). Car airbags were conceived in the 1950's and early versions involving electromechanical sensors and pyrotechnic inflators were developed and introduced in the 1970's and 1980's. In the US, regulatory mandates requiring passive restraints were debated from 1970 until 1984, the goal during this period according to NHTSA (1997) being to provide a passive means to deal with extremely low rates of safety belt usage. In the US, despite “vigorous efforts to promote [their] use,” as of 1984, the belt usage rate was only 14 percent.

In 1984 US/DOT issued mandatory performance requirements for “automatic restraints,” to be phased in beginning in 1987, and involving either automatic belts or airbags. Specifically, FMVSS 208 required two rigid barrier crash tests for airbag-equipped vehicles: one with belted dummies and one with unbelted dummies.

During this period, NHTSA (1997) indicates that US belt usage rapidly increased, due to state mandatory usage laws, to nearly 60 percent in 1991. The belt usage rate in 2000 was 71 percent.

In 1991, Congress directed NHTSA to amend FMVSS 208 such that the automatic occupant protection would be “an inflatable restraint,” with 100 percent phase-in for passenger cars by 1998.

However, the “aggressive” (ie, rapid, large mass flow rate) US airbag test requirements aimed at unbelted 50th percentile male occupants were not modified during this period, despite the diversity of occupant sizes amongst and increased belt usage by the population.

In Europe, Japan and other regions, car airbags were available as optional and then standard equipment on some vehicle models. Stricter mandatory seat belt laws in most other countries meant that airbags could function as truly “supplemental restraint systems,” which had been the vision of many designers from the beginning.

During the same time frame, as the number of US airbag-equipped vehicles passed 56 million in 1996, reported incidents of airbag-induced injuries and fatalities began to increase. As of 1998, there were substantial numbers of lives being saved by airbags, but also significant numbers of lives being lost, due to the action of airbags, according to US data as indicated in Table 2.

Table 2.
Example Risk and Benefit Data for US Car Airbags, Fatal Only
(NHTSA, 1998, from Iijima et al, 1998)

Occupant Category	Lives		Risk/Benefit (%)
	Saved (Benefit)	Lost (Risk)	
All	2920 ¹	94 ²	3
Drivers	2536	36	1
Adult passengers	384	4	1
All passengers	384 ¹	45 ²	12

Notes

- 1 Assumes no child lives saved by airbags.
- 2 Excluding children in rear facing child safety seats.

In response to this emerging situation, the US/DOT/NHTSA took the following steps (NHTSA, 1998):

- May 1995: Allowed manufacturers to install airbag on-off switches
- October 1995: Issued strong warning that those not wearing a seat belt may be injured or killed by an airbag.
- May 1996: Initiated an airbag safety campaign involving manufacturers, insurance companies and safety groups.
- November 1996: Required new airbag warning labels on all vehicles.

- March 1997: Allowed manufacturers to de-power airbags, by providing an alternate sled testing procedure in place of the unbelted barrier test.
- November 1997: Allowed certain consumers to purchase an airbag on-off switch.
- September 1998: Issued proposal for revised airbag testing procedures, intended to reduce risk of airbag-induced injuries.

NHTSA also requested that an in-depth, scientific review and analysis of current and future car airbag technology be done by the US/NASA/Jet Propulsion Laboratory (Phen et al, 1998). The purposes of this study were to “evaluate airbag performance, [and to] establish the technological potential for improved (smart) airbag systems.”

The JPL report states that “This automotive safety system is injuring occupants because of the widely variable nature of motor vehicle crashes and the performance of current airbag systems,” and that “Airbag systems presently in the US vehicle fleet have been optimized for the 50th percentile male without a safety belt in a 48 km/h (30 mi/h) rigid frontal barrier crash at ambient temperature.” However, “To meet a goal of protecting the public from airbag-induced injury during vehicle crashes, airbag performance must be characterized and understood:

- 1) for occupants of different sizes who sit at different distances from the airbag module,
- 2) for vehicle crashes of differing severity ranging from low speed vehicle-to-vehicle crashes to high speed rigid barrier crashes,
- 3) for different ambient temperatures, because temperature has a large effect on inflator gas output characteristics, and
- 4) for belted and unbelted occupants.”

In particular, JPL found that “The performance of present airbag systems can be severely degraded by changes in any of the four parameters mentioned above,” and “A restraint system, such as an airbag, must respond to this highly varied and unpredictable need for protection” (italics added).

Concern was also expressed regarding the car crash test results of Transport Canada, which indicated that late airbag deployment (ie, more than 40 ms after impact) and increased risk of injury occurred in various types of “soft” crashes.

In the technology area, the JPL report indicated that the industry is developing a variety of promising technologies to address this inherent and large variability in usage conditions. Beginning in model year 2001 and progressing into the future, these were expected to include: pre-crash sensing, improved crash severity sensors, sensing diagnostic modules, belt use sensors, belt spool-out sensors, seat position sensors, occupant classification sensors, occupant proximity motion sensors, improved computational systems, non-azide propellants and heated gas inflators (allowing lower mass airbag fabrics), hybrid inflators (for reduced variability), multi-stage inflators (which however might increase performance variability), inflators with "tailor-able" mass flow rates, improved fabrics and coatings (to reduce bag mass, seams and vents), new bag shapes and compartmentalization, improved controlled bag venting systems, wider use of belt pre-tensioners, belt load limiting devices and inflatable belts, and improved system reliability.

In May 2000, NHTSA issued a revision of the frontal crash protection standard FMVSS 208 (NHTSA, 2000), intended to address many issues of airbag induced injury risk. This includes the expansion of frontal airbag testing with 43 new test procedures, including those for other sized occupants, out-of-position occupants, non-crash deployment and inflation suppression systems (see Appendix 2). This provides one type of checklist for any airbag systems, including motorcycle feasibility prototypes, which seek both to reduce occupant injuries in crashes and to avoid injuries from the airbag itself.

In addition, in the last several years the International Organization for Standardization (ISO) and other standards groups have formalized test procedures for use in developing and evaluating car airbags, which can also serve as a reference checklist for motorcycle airbag feasibility studies.

Overall, it seems likely that research into motorcycle airbag feasibility should anticipate similar complex factors with regard to the variability of the motorcycle crash environment, and the need to accommodate this with similar types of advanced airbag technology and test procedures.

RELEVANT MOTORCYCLIST FACTORS AND CONSIDERATIONS

Research to date by the motorcycle industry and others indicates the following key factors that should be addressed in motorcycle airbag feasibility research.

Variations in Motorcycle Layout

Worldwide and within regions, there is a more than 10-to-1 variation in motorcycle mass among vehicles in use (eg, less than 50 kg to more than 500 kg), with corresponding large differences in dimensions and shapes.

In addition, unlike passenger cars, there is a wide diversity of user-preferred seating layouts among motorcycles, with regard to the relative positions of the handgrips, seat and foot rests. These can range from a forward-leaning rider in sport motorcycle layouts, with the rider's chin upward and feet rearward; to an upright rider in touring motorcycle layouts; to a rearward-leaning rider in cruising motorcycle layouts, with the rider's chin downward and feet forward.

All of these variations may affect the relative benefits and risks of an airbag, or in other words, airbag feasibility. Even if airbags are found to be feasible for one type of motorcycle, they might not be found to be feasible for all motorcycle sizes and types.

Variations in Rider Sizes and Positions

As with car drivers and passengers, there is a wide range of motorcycle rider and passenger sizes and weights worldwide, along with wide variations in motorcycle types.

Likewise, there can be wide variations in rider and passenger riding positions, for personal comfort and performance reasons. These can vary with speed, from an upright or leaning rearward position at low speeds to a forward crouch; and with hips centered or shifted left or right. In addition, less experienced riders sometimes tend to allow the motorcycle to lean or roll beneath them, whereas more experienced riders tend to remain in the motorcycle centre plane, or to lean into the turn more than the motorcycle itself.

The car airbag experience discussed previously indicates that body size and position have extremely important effects on airbag-induced injuries as well as airbag effectiveness.

Helmet Interaction

Helmets are the primary protective devices available to motorcyclists, and properly certified and fitted helmets have been found to be effective in reducing rider head injuries in accidents. Closed face helmets (ie, helmets with a chin bar) have been found to be especially effective in reducing head frontal impact injuries.

A very wide range of motorcycle helmet shapes, sizes and masses is available and in use worldwide.

Unlike accommodating head-to-airbag contact that occurs with car airbags, motorcycle airbags must contact and interact with a wide variety of helmets. In particular, it is possible for a still-inflating airbag to catch under the chin bar of a particular helmet, or between the helmet and the clavicle region. This may accelerate the helmet mass upward or rearward, whilst the helmet chinstrap remains fastened beneath the head. Exploratory tests with helmeted forward-leaning cadavers by Ramet et al (1994) indicated that the action of the motorcycle airbag against the helmet resulted in neck fractures or dislocations in 4 out of 4 cadavers.

Interaction of a deploying airbag against the side of a helmet chin bar, which could apply torsional loads to the neck, has not yet been assessed.

Unknown Effectiveness in Accidents

Motorcycles tend to rotate much more than cars in collisions (ie, in roll, pitch and yaw), which can move a motorcycle-mounted airbag away from the rider.

In addition, unlike car drivers who are typically restrained by a seat belt, motorcycle riders tend to move in a different direction than the vehicle during collisions, due to the previously mentioned motorcycle rotations and the absence of a seat belt. The latter would tend to have harmful effects on riders of conventional motorcycles (Yamamoto, 1980).

In addition, in accidents, airbags are aimed at reducing head and other injuries. However, rider

injuries, including head injuries, are more frequently caused by rider/ground contact than rider/car contact (Hurt, 1981). Airbag effects on rider/ground contact are complex and difficult to generalize. Iijima (1998) reported that a prototype airbag increased neck injuries at head/ground contact, due to the somersaulting motion of the rider.

Need for Common Test and Analysis Methods for Airbags

It is obvious that one could arbitrarily select a test condition and analysis method that would indicate that a given airbag is beneficial; or select another method that would indicate that it is harmful.

It is therefore essential to define a common methodology for motorcycle airbag feasibility evaluation, in order to avoid conflicting results.

A starting point for such common methods is International Standard ISO 13232 (1996). The purpose of ISO 13232 is to define common methods for analyzing the feasibility of devices fitted to motorcycles and intended to protect the rider in impacts with passenger cars. Since its approval in 1996, ISO 13232 has been used by both industry and government groups to conduct motorcycle protective device research.

Originally developed in order to harmonize motorcyclist leg protector research, the scope of ISO 13232 includes all motorcycle-mounted devices intended to protect riders in collisions. The Standard is now undergoing its first revision by ISO/TC22/SC22/WG22, in order to address additional important issues relevant to inflatable or deployable protective devices (ie, incorporating a new, more humanlike dummy neck, neck injury criteria, injury risk-benefit analysis methods, etc), based on existing technology and research.

DIFFERENCES BETWEEN CAR AND MOTORCYCLE AIRBAG FACTORS

Another way to express the differences between car and motorcycle airbag factors is from a car-centred viewpoint, namely that cars, typically, and their occupants:

- Involve no helmets that can interact with the airbag in various ways;

- Rotate much less in collisions, which limits the motion between the occupant and the airbag;
- Have a “primary restraint (belt) system,” which allows the airbag to function in a less demanding way, as a “supplemental restraint system” (SRS). Seat belts, as already mentioned, would have extremely harmful effects if fitted to conventional motorcycles;
- Have seat backs, which provide a reaction surface for the occupant and seat belt;
- Have an enclosed structure which can support the airbag, the seat belts and the seat back, and which further limits the motion of occupants in crashes;
- Have typical occupant seating positions that are more rearward leaning, with chin closer to the chest (reducing the neck area exposed to airbag forces), compared to most motorcycles;
- Have internal areas that are less exposed to environmental elements (eg, water, solar radiation, shock and vibration, high air velocities, etc) compared to motorcycles.

CONSIDERATION OF AIRBAG “FEASIBILITY” CRITERIA

For a vehicle safety device to be “feasible” in modern industrialized societies means that the injury-reducing benefits of the device must be very much larger than the injury-increasing risks from the device (eg, Thompson et al, 2000; ISO 13232-1, 1996). Indeed this is the same principle applicable to pharmaceuticals and medical devices approved worldwide each year. This requirement has evolved from the ancient medical dictum “First do no harm.”

A proposed amendment to ISO 13232-5 specifies improved methods for risk-benefit (R-B) analysis (see Appendix 1) and provides suggested guidelines for general R-B criteria that are considered to be useful as references for feasibility research purposes.

In effect, such R-B criteria mean that for motorcycle airbags to be “feasible,” the probabilities and changes in injuries due to the device should be analyzed; and the probable risks should be much smaller than the probable benefits, when summed across an estimate of the foreseeable usage conditions.

For motorcycles, such protective device feasibility analyses should be done with the

standardized testing and simulation methods of ISO 13232, which are being revised to reflect updated knowledge and priorities.

In modern industrial societies, such feasibility analyses should not be done with trial-and-error “experiments on the public.”

TOOLS FOR RESEARCHING MOTORCYCLE AIRBAG FEASIBILITY

Based on these “feasibility” criteria, there is a need for a common, suitably broad and realistic methodology for motorcycle airbag feasibility research, in order to avoid harmful airbags, and conflicting results.

General Needs

Since the goal is to assess airbag risks and benefits across the conditions of foreseeable and realistic use, full-scale impact tests with realistic opposing vehicles and objects at a variety of impact conditions are needed, along with calibrated computer simulations to interpolate between impact conditions.

Tools Used to Date

To date, a variety of tools have been used in airbag feasibility research (eg, Bothwell, 1973; Rogers, 1994; Ramet, 1994; Chinn, 1996; Iijima, 1998), and these have included:

- Stationary motorcycle airbag deployment tests, in order to approximately tune a prototype airbag for inflation timing, to examine its potential for injury reduction and to evaluate the effects of unintended and out-of-position deployments;
- Sled tests, in order to further tune a prototype airbag and rider motions for a condition roughly simulating a frontal, 90 degree impact against a stationary object, with various rider positions;
- Full scale impact tests, against a standardized car, with and without an airbag, as in ISO 13232, with standardized impact configurations, motorcyclist crash dummy, helmet, position, etc., in order to evaluate device effects across several crash conditions and to calibrate computer simulations across a range of impact conditions;

- Computer simulations, in order to enable evaluation of the injury risk-benefit across the full range of impacts representing real world accidents, in order to interpolate between the full-scale tests, and for risk-benefit analysis purposes.

These are basically the same tools as are used in car airbag development, by car manufacturers, although an additional factor for cars is the need to meet various legislative requirements.

Standardization of Research Tools

In order for airbag or any other device feasibility research to progress, it is considered necessary to reach a consensus on test and analysis methods to be used in such research. Without standardization of research methods that have a sound, scientific basis, it is likely that different conclusions will be reached about feasibility and injury risks and benefits.

Generally speaking, it is essential that such tools and methods:

- Reflect a consensus of experts and users (Harvard Center for Risk Analysis, 1992);
- Reflect available knowledge and tools;
- Protect and not harm users (and in particular vulnerable users, such as smaller riders and out-of-position riders)

Some of the aforementioned tools have already been standardized in ISO 13232, for example, full-scale impact tests against opposing vehicles, and calibrated computer simulations. There is an interest in revising these:

- To simplify them, when scientifically justified;
- To reflect updated knowledge (eg, human and dummy crash responses, injury criteria, accident data, etc);
- To reflect additional factors of importance for motorcyclist “inflatable or deployable” protective devices.

Therefore, for airbag feasibility research in particular, the following revisions have been proposed to be added to ISO 13232:

- More human-like dummy neck, with three dimensional response which is more similar to human volunteers;

- Neck injury criteria, based on data from 71 fatal and 352 non-fatal motorcycle accidents, detailed autopsies, calibrated computer simulations, and statistical analyses;
- Updated standardized opposing vehicle, helmet, and impact configurations based on accident data;
- Airbag feasibility checklist, as summarized in Table 3, for groups doing research in this area.

**Table 3.
Airbag Feasibility Checklist**

Item	Description
1	<ul style="list-style-type: none"> - Further consideration of impact configurations defined in ISO 13232 in order to include: <ul style="list-style-type: none"> - Non-crash impacts, in which the airbag should not deploy due to: <ul style="list-style-type: none"> - Road disturbance - Other obstacles - Crash impacts, in which the airbag should deploy due to impacts with: <ul style="list-style-type: none"> - Opposing vehicle - Opposing objects - New accident databases containing sufficiently detailed information on impact configurations - Full scale test selection based on: <ul style="list-style-type: none"> - Nature of the device - Diversity of motions for computer simulation calibration - Simplification of impact configurations if scientifically justified
2	Evaluation of effects of intended deployments in impacts with: <ul style="list-style-type: none"> - Opposing vehicle - Opposing objects
3	Evaluation of effects of unintended deployments
4	Evaluation of ability to suppress deployments in non crash (ie, non injurious) conditions, and determination of the maximum delta V for such non crash conditions
5	Evaluation of effects on different rider sizes, especially small riders (eg, in Items 2 and 3)
6	Evaluation of effects of different riding positions (eg, in Items 2 and 3) that are observable in actual motorcycle use, eg, hip shift, upper body lean, head rotation
7	Evaluation of effects in the presence of pillion passengers (on rider; on passenger)

8	<p>Evaluation of other potential airbag related risks:</p> <ul style="list-style-type: none"> - Burns - Facial abrasions - Arm/hand fractures - Fuel system fire potential - Hearing loss - Toxicity to rider, rescue or recycling personnel
9	<p>Environmental resistance (Note: these may be mainly developmental issues):</p> <ul style="list-style-type: none"> - Water & moisture - Vibration & shock - Temperature - Solar radiation - High velocity air - Contaminants (dust, fuel, lubricants) - Electromagnetic interference - Aging
10	<p>Injury risk-benefit evaluation across foreseeable usage conditions, considering:</p> <ul style="list-style-type: none"> - Probability of a given event occurring - Effects of the airbag if the event occurs <p>Guidelines:</p> <ul style="list-style-type: none"> - Injury benefits should be much greater than the injury risks - Average injury benefit per beneficial case should be greater than the average risk per harmful case

Many of the topics in Table 3 are subjects of active or planned research within the motorcycle industry, and/or of discussion within ISO/TC22/SC22/WG22. Generally speaking, it is desirable to develop common and sound methods for investigating such topics, in order that common conclusions may be reached regarding airbag benefits and risks.

In addition, from a technology viewpoint, it is possible that some or many of these topics may be addressed by adaptation of advanced car airbag technologies, as they emerge.

CONCLUSIONS AND RECOMMENDATIONS

Research into the feasibility of motorcycle-mounted airbags has occurred over the last 30 years. To date, an airbag prototype which is beneficial and not injurious to riders of all sizes has not yet been found. Much of this research has been exploratory and involves the development of various airbag

concepts as well as improvement and standardization of the research methodology used to evaluate such prototype systems.

Related experience in the car airbag field has indicated that first-generation US systems were tuned for a 50th percentile unbelted male dummy—similar to the dummy used in all of the motorcycle airbag feasibility research to date—and that in actual real world accidents such systems can cause serious or fatal injuries among smaller adults; among out-of-position occupants of all sizes; in so-called “soft” collisions which result in late deployment of the airbag; and due to variations of inflator characteristics due to ambient temperature. Most of these factors seem applicable to motorcycle airbags, but have not yet been evaluated. In a similar way, car airbag countermeasures involving advanced sensing and control have not yet been investigated for motorcycles.

In addition, there are many airbag application factors that are different for motorcycles than for cars. These include: helmet interaction with the airbag; greater vehicle rotations in crashes; absence of seat backs, seat belts and enclosed protective structures in conventional motorcycles; wider range of seating layouts and preferred seating positions (eg, more forward leaning) than in cars; and greater exposure to environmental elements (eg, water, solar radiation, shock and vibration, etc).

A general method and guidelines for protective device “feasibility” has been proposed to be added to the existing standardized research test and analysis methods of ISO 13232, for protective device research. This recommends that the probable injury risks of any safety device be much smaller than the probable injury benefits of a device, when summed across an estimate of the foreseeable usage conditions. This is consistent with criteria used in the medical and pharmaceutical intervention field, and the ancient medical dictum “First do no harm.”

Other updates to ISO 13232 important for motorcycle airbag research are in process, including a new dummy neck and neck injury criteria. In addition, an “airbag feasibility checklist” is planned to be added for research into deployable devices, which involves evaluation of the effect of: other impact and non-impact configurations; intended and unintended deployment; suppression of deployment in non-crash conditions; different rider sizes, especially small riders; different riding positions;

pillion passengers; other risks such as burns, fire potential, arm fracture, etc; and environmental resistance.

Together, such methodology improvements are intended to provide a sound and positive basis for research into improving rider protection and avoiding unintended consequences.

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APPENDICES

1. SUMMARY OF RISK-BENEFIT ANALYSIS METHOD (Condensed from ISO 13232 amendment, (ISO/TC22/SC22/WG22 N255, 2000)

Benefit = Average decrease in injury index x_j
 $= 1/N \sum_{l=1, Nben} (-\Delta x_{l,j} * FO_l)$

Risk = Average increase in injury index x_j
 $= 1/N \sum_{k=1, Nrisk} (\Delta x_{k,j} * FO_k)$

where

N = Total number of events
 Nben = Number of events in which the device is found to be beneficial (ie, results in a decrease in injury index value)
 Nrisk = Number of events in which the device is found to be beneficial (ie, results in a decrease in injury index value)

Δx = Change in injury index value (protective device – baseline)

FO = Frequency of occurrence of a given event

2. LIST OF POTENTIALLY RELATED CAR AIRBAG TEST AND ANALYSIS METHODS

Table 2.1
Additional Car Airbag Tests
Needed to Reduce Airbag-Induced Injury Risk,
May 2000 Amendment to US FMVSS 208

Section	Test Type	Dummy		Belted
		Driver	Pass.	
5.1.1	Frontal rigid barrier	50 P male	50 P male	Yes
5.1.2	Frontal rigid barrier	50 P male	50 P male	No
5.13.1	Whole vehicle sled	50 P male	50 P male	No

5.14.1 5.16	Frontal rigid barrier	5 P female	5 P female	Yes
5.14.2 5.16	Frontal rigid barrier	5 P female	5 P female	No
5.18	Frontal offset deformable barrier	5 P female		Yes
19	Static test of automatic suppression		12 month infant	Child seat
19	Low risk deployment test		12 month infant	Child seat
21 21.2	Static test of automatic suppression		3 year old child	No
21 27	Dynamic automatic out-of-position suppression test		3 year old child	Child seat
21 27	Dynamic automatic out-of-position suppression test		3 year old child	Child seat, belted, not anchored
21 27	Dynamic automatic out-of-position suppression test		3 year old child	Child seat, not belted, not anchored
21 22.4	Low risk deployment test		3 year old child	No
22.5	Barrier tests for staging and timing of low risk deployment tests		NA	NA
23 23.2	Static test of automatic suppression		6 year old child	No

23 27	Dynamic automatic out-of-position suppression test		6 year old child	Child seat, belted, anchored
23 27	Dynamic automatic out-of-position suppression test		6 year old child	Child seat, belted, not anchored
21 27	Dynamic automatic out-of-position suppression test		6 year old child	Child seat, not belted, not anchored
21 27	Low risk deployment test		6 year old child	No
21 24.4	Low risk deployment test		6 year old child	No
24.3	Static test of automatic suppression		5 P female	No
25 27	Dynamic automatic out-of-position suppression test	5 P female		No
25 26 22.6	Low risk deployment test	5 P female		No
28.1	DASS test moving dummy	5 P female		No
28.2	DASS test moving dummy		3 year old child	No
28.2	DASS test moving dummy		6 year old child	No
29	Static test of automatic suppression		Live, 5 P female	No
29	Static test of automatic suppression		Live, 3 year old child	No

29	Static test of automatic suppression		Live, 6 year old child	No
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Table 2.2
List of Relevant ISO standards and Documents,
Car Airbags

ISO/TR 10982 (1998)	Road vehicles-Test procedures for evaluating out-of-position vehicle occupant interaction with deploying airbags
ISO/TR 14933 (1999)	Road vehicles-Test procedures for evaluating occupant interaction with deploying side airbags
ISO 3560 (rev 2000)	Road vehicles-Frontal fixed barrier or pole impact test procedure
ISO 10997 (1997)	Passenger cars-Side impact with deformable moving barrier-full scale test
ISO/TR 15827 (2000)	Road vehicles-Test procedures for evaluating arm-airbag interactions with instrumented dummy arms
ISO/CD 15828 (2000)	Road vehicles-Dynamic side impact crash test procedures for evaluating occupant interactions with side airbags for a pole impact simulation
ISO/CD 15829 (2000)	Test procedures for offset frontal crash testing
ISO/CD 3984 (2000)	Moving barrier rear collision test method
SAE J1727 (1998)	Road vehicles-Injury calculation guidelines
ISO 7863 (rev 2000)	Passenger cars-Sled test procedure for evaluating restraint systems in simulated frontal collisions