Federal Office of Road Safety

Document retreival information

Report No.	Date	Pages	ISBN	ISSN
OR 12	June 1992	57	0 642 51092 X	0158-3077

Title and Subtitle

Review of Passenger Car Occupant Protection — Main Report

Author(s)

Seyer, K. A., Makeham, P. M., McLennan, D. J.

Performing Organisation(Name and Address)

Federal Office of Road Safety
15 Mort Street
CANBERRA ACT 2601

Available from

Federal Office of Road Safety
GPO Box 594
CANBERRA ACT 2601

Abstract

This reports on a $1 million standards development program by the Federal Office of Road Safety to review and improve occupant protection in passenger cars. It is part of a Federal Government initiative to reduce road trauma through road safety research. The aim of the review was to identify the causes of injuries to vehicle occupants and to help develop a cost effective strategy to reduce these injuries. This included analysis of actual injuries and a possible range of countermeasures. The main outcome of the review was the release of a new draft Australian Design Rule for frontal impact protection which is expected to bring about the introduction of emerging safety technology such as airbags into new vehicles. The review also recommends further work into side, offset frontal and rollover impacts together with examination of improved safety restraints and child safety.

Keywords

OCCUPANT PROTECTION, ROAD SAFETY, ADR, FRONTAL IMPACT

Notes:

(1) FORS Research reports are disseminated in the interests of information exchange.

(2) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth Government.

(3) The Federal Office of Road Safety publishes four series of research report

- (a) reports generated as a result of research done within the FORS are published in the OR series;
- (b) reports of research conducted by other organisations on behalf of the FORS are published in the CR series.
- (c) reports based on analyses of FORS' statistical data bases are published in the SR series.
- (d) minor reports of research conducted by other organisations on behalf of FORS are published in the MR series.

FORS Research

Review of Passenger Car Occupant Protection
Main Report — OR 12

Seyer, KA
Makeham, PM
McLennan, DJ

Transport and Communications
Federal Office of Road Safety

Acknowledgements

The authors gratefully acknowledge the following organisations and their staff for their time and expertise in conducting the various projects which make up the Federal Office of Road Safety's review of passenger car occupant protection:

Monash University Accident Research Centre
Ernst and Young
Kennerley Digges and Associates
General Motors-Holden's Automotive Pty Ltd
New South Wales Roads and Traffic Authority Crashlab
Dwyer Leslie Pty Ltd

The authors also wish to acknowledge the efforts of staff in the Federal Office of Road Safety who assisted in managing and executing the various projects.

Executive summary

Introduction

The Federal Government has a strong commitment to the safety of passenger cars.

The Australian Design Rules (ADRs) set down a comprehensive range of performance and design requirements for motor vehicle safety and are among the most stringent in the world.

The current Australian Design Rules are closely aligned with the United Nations international standards which are widely used particularly in Europe and Japan. This provides safety benefits to the consumer and assists the Government's plan to improve the efficiency of the automotive industry.

The first set of ADRs were implemented in 1969. Since that time, there have been significant reductions in fatalities through the ADRs and other Government initiatives such as compulsory seat belt wearing and drink driving campaigns.

The Federal Government is determined to achieve further reductions in road trauma and has allocated $10 million for road safety research and public education over a three year period.

As part of this package, the Federal Office of Road Safety (FORS) has conducted a review of ways to improve protection for passenger car occupants. The aim of the review was to identify the causes of injuries to vehicle occupants and to help develop a cost effective strategy to reduce these injuries. This included analysis of actual injuries and a possible range of countermeasures.

In 1989, the Federal Office of Road Safety commissioned a major study to determine how the Design Rules were performing and recommending what improvements can be made.

The study (FORS Report CR 95 "Passenger Cars and Occupant Injury") *was carried out by the Monash University Accident Research Centre and* showed that despite the improvements in vehicle safety, occupants were still being injured by contact with parts of the passenger compartment.

To follow on from this study, the Federal Office of Road Safety embarked on a $1 million standards development program incorporating the following main elements:

- Crash testing of seven Australian produced vehicles to provide baseline data

- Autoliv in Germany, a world leader in seat belt and airbag technology, to analyse the data to develop and provide enhanced safety systems to be used for further tests
- Three further crash tests on one Australian vehicle model fitted with these enhanced safety systems
- Monash University Accident Research Centre, in conjunction with Ernst and Young, and Kennerley Digges and Associates, to study the cost effectiveness and feasibility of safety options
- A study by Dwyer Leslie Pty Ltd on the feasibility and methodology of conducting a consumer willingness to pay for safety measures
- Laboratory tests on a range of new technologies to be undertaken by the NSW Roads and Traffic Authority

This report brings together the findings of the various aspects of the FORS research program.

Crash Test Program

FORS Report OR 11 "Review of Passenger Car Occupant Protection — Main Report" describes the three phases of the crash test program.

The first phase of the crash test program was conducted to provide base data on seven Australian production vehicles using the test procedures of the United States Federal Motor Vehicle Safety Standard 208 (FMVSS 208), with instrumented dummies restrained in a full frontal crash test at 48 km/h. One vehicle model was then chosen for a series of further tests.

The second phase involved Autoliv in Germany, a world leader in seat belt and airbag technology, to analyse the data and develop three combinations of new restraint technology. The components used were airbags, buckle pretensioners, webbing clamp retractors and energy-absorbing steering wheels.

An important element of the Autoliv work was to optimise the performance of these components in the vehicle model chosen. International experience has demonstrated that these devices will not perform effectively unless they are optimised for the vehicle in which they are to be installed.

The third phase involved the crash testing of three more vehicles fitted with these enhanced safety systems.

The vehicle models used in the crash tests were built to conform to the current Australian Design Rules for vehicle safety and provided a level of safety comparable to that offered by equivalent vehicles in Europe and Japan. There were no unexpected structural failures observed during the crash tests.

The outcome of the crash tests in the third phase showed that there were significant improvements possible with the range of emerging technology when properly engineered into a vehicle when assessed against the injury parameters specified in FMVSS 208.

Laboratory Tests on Emerging Safety Technology

These tests were conducted using the crash sled test facility at the New South Wales Roads and Traffic Authority's Crashlab.

The tests were conducted using the various countermeasures identified in FORS Report CR 95 "Passenger Cars and Occupant Injury" fitted to a part of a vehicle structure which was mounted on a deceleration sled which simulates a crash.

Tests were conducted with the countermeasures fitted both individually and in various combinations with one another. The components were not specifically engineered for the particular vehicle model nor was the crash pulse that of the actual vehicle.

The tests indicated that in many instances, there was no improvement in restraint performance. In some cases, there was a decrease in safety.

The report highlighted the significance of the interaction between the different components of the total vehicle restraint system, namely, the effects of seat location, cushion stiffness, steering wheel position and seat belt performance.

The work confirmed the complexity of developing an optimised safety package for a particular vehicle.

Feasibility Study of Occupant Protection Measures

The aim of this study (FORS Report CR 100 "Feasibility of Occupant Protection Measures") was to assess the costs and benefits of a mix of countermeasures identified in FORS Report CR 95 "Passenger Cars and Occupant Injury". This information would provide guidance in developing improved ADRs for frontal impact protection in passenger cars.

The countermeasures included restraint system improvements (belt pretensioners, webbing clamp retractors, improved seat belt geometry, and a seat belt warning system), supplementary airbags (fullsize and facebags) for driver and front seat passengers, injury reductions from the steering assembly, better instrument panel design for front seat occupants, and improved padding and structures.

Discussions were held with industry to examine any potential difficulties associated with the introduction of the various countermeasures.

Similarly, information from local and overseas vehicle manufacturers and suppliers was used to establish likely costs to the consumer of the various measures. Costs were adjusted for economies of scale where appropriate.

Likely injury reductions were estimated from national crash statistics, information from the Crashed Vehicle File (FORS Report CR 95 "Passenger Cars and Occupant Injury"), and indications of improved safety performance based on published international road safety literature. Where improved performance was unknown, an estimate of likely savings was made by an expert panel. Reductions of injury costs were subsequently determined.

Calculations included the benefits to be derived from airbags for the small proportion of front seat occupants in Australia who do not wear seat belts (6%). The proportion of persons killed or injured who were not wearing belts in a crash is higher (17%) than the proportion in the driving population as a whole. Belted occupants account for most of the total benefits estimated for airbags (77%).

Benefit Cost Ratios were then derived for countermeasure packages which included combinations of driver airbag (both fullsize and facebag), energy absorbing steering wheel, belt pretensioners, webbing clamp retractors, and improved seat and seat belt design.

Study on Consumer 'Willingness to Pay' for Safety Features

The aim of the project was to look at the feasibility and methodology to conduct and analyse a survey on a sample of recent new car buyers to assess the community's 'willingness to pay' for improved safety features.

The study will be structured to describe a hypothetical market to an individual in a way that places that individual in a position of being able to purchase a particular commodity. The valuation questions request bids from individuals for stated changes in this carefully defined commodity. In effect, the person is confronted with the prospect of being able to purchase the change.

In this case, the commodity will be packages of safety measures set out in the Monash University Accident Research Centre's report on the cost benefits of these packages. The change is the degree of injury mitigation associated with the various packages, and what the cost is.

The sample group will be selected from people who have purchased a new, mass market family car recently (about 12 months ago), so that the decision making process is likely to be clearly remembered.

The survey will be tailored so that a threshold will be produced for what the community is prepared to pay for safety features.

A separate report on the survey and analysis of its results will be prepared so it can be considered in the Government's decision making process.

Side Impact and Other Studies

The extension of the Crashed Vehicle File to side impact is due for completion end of 1992. In the meantime, FORS is monitoring overseas developments for a new dynamic side impact test as well as participating in discussions in the international forum at Geneva.

An improved ADR for child restraints will be introduced in 1993 which will facilitate the installation and interchangeability of child restraints in passenger cars.

FORS is participating in an international committee to develop a uniform test procedure for offset frontal impact testing.

No work is being done in Europe in relation to rollover crashes. The US is examining a new requirement for testing the stability of vehicles. In Australia, the Federal Office of Road Safety is working with the motor industry to develop a code of practice for roof strength based on the US regulations.

Conclusion

The vehicle models used in the crash tests were built to conform to the current Australian Design Rules for vehicle safety and provided a level of safety comparable to that offered by equivalent vehicles in Europe and Japan. There were no unexpected structural failures observed during the crash tests.

However, the results demonstrated that there is room for improvement.

The crash test program examined some of the countermeasures to achieve these improvements in occupant protection and showed that the implementation of a new Australian Design Rule for frontal impact protection which sets performance requirements based on the established injury parameters in US Federal Motor Vehicle Safety Standard 208 would achieve these improvements.

The crash test program also demonstrated that considerable development work would be required to achieve performance levels high enough to give manufacturers confidence that all production vehicles would meet the requirements of a regulatory regime based on the American standard. The laboratory tests in NSW Crashlab confirmed that it was necessary to properly engineer components into vehicles. The benefits of these new safety items will not be realised unless their performance is carefully optimised for individual vehicle models.

The feasibility study showed that a number of combinations of these countermeasures for improving occupant safety, including the ones examined in the crash test program, yield a Benefit Cost Ratio of greater than one.

There is further work to be done in the areas of side, offset frontal and, to a lesser extent, rollover impact protection. This is expected to lead to regulatory requirements in the coming years.

The outcome of the various elements of this program support a move to a performance based requirement specifying established injury parameters rather than the traditional approach of specifying individual components.

In summary, the program confirmed that an Australian Design Rule based on FMVSS 208 injury criteria would lead to significant improvements in occupant protection which would bring about the fitment of a range of cost effective emerging safety technology including airbags.

Recommendations

The following recommendations to improve occupant protection in passenger cars are made in the context that there are uniform compulsory seat belt regulations in Australia, with a wearing rate of over 90% in front seats:

- It is recommended that a new Australian Design Rule for full frontal impact protection be released for public comment which sets performance requirements based on the established injury parameters in US Federal Motor Vehicle Safety Standard 208. The proposed introduction date for the new ADR to be 1 July 1995.
- It is recommended that support be given to Australia's participation in the European Experimental Vehicle Committee's work to develop requirements for a global offset frontal impact test procedure.
- It is recommended that further work be carried out in Australia and developments be monitored overseas in the area of side impact with a view to adopting one or both of the dynamic side impact regulations developed by the US and European authorities.
- It is recommended that action be taken by the Federal Office of Road Safety in conjunction with the Federal Chamber of Automotive Industries to introduce a code of practice on compliance with the static roof crush requirements in US FMVSS 216.
- It is recommended that Australia monitor developments in the USA for a new dynamic rollover test.
- It is recommended that the use of lap only seat belts be examined with a view to considering requirements for the installation of lap sash seat belts in all seating positions of passenger cars.
- It is further recommended that work continue to encourage, as much as possible, the integration of child restraint systems into the design of the vehicle.

Table of contents

1 Introduction

Governments in Australia have for many years been concerned about road safety.

Whilst the progressive reduction in fatalities per 10,000 vehicles indicates steady improvements in vehicles and road systems from the 1930s, total road fatalities in the 1960s increased as a result of greatly increased usage of motor vehicles. This increase in road fatalities provided the catalyst for Governments in Australia and elsewhere to introduce far more stringent vehicle safety requirements.

This led to the first set of Australian Design Rules being implemented in 1969.

1.1 The Australian Design Rule System

The Australian Design Rules (ADRs) (1) set down the performance and design requirements for motor vehicle safety.

The ADRs take force nationally under the Federal Motor Vehicle Standards Act and are administered under a "type approval" system by the Federal Office of Road Safety (FORS). Under this system, each model of a particular vehicle design must be shown to comply with the ADRs. The ADRs are approved as "National Standards" by the Federal Minister for Land Transport under the Motor Vehicle Standards Act 1989 and tabled in the Federal Parliament.

The Act applies to vehicles prior to first supply to the Australian market. Control of vehicles which are already in service is the responsibility of the States and Territories.

The States and Territories are involved with the Commonwealth in the areas of standards development and the certification of vehicles to these standards.

The arrangements to provide assurance that vehicles sold in Australia comply with the ADRs cover the following areas:

- Development of standards
- Certification of vehicles to the standards
- Audit of vehicle manufacturing and testing facilities
- Investigation of safety defects and recall

1.1.1 Development of Standards

The ADRs cover a wide variety of safety requirements such as seat strength, seat belts, crashworthiness, glazing, brakes, tyres and other features to improve occupant protection. They also set out requirements for vehicle exhaust emissions and noise.

There are currently 68 ADRs relating to the various vehicle categories of passenger vehicles, motorcycles, commercial vehicles, omnibuses and trailers.

It is the Federal Government's policy to harmonise, wherever possible, with international standards unless there are significant safety grounds to do otherwise. At present, over 60% of the ADRs are aligned with international standards, predominantly the European ECE regulations. The remainder, especially in the vehicle exhaust emissions area, mirror US regulations.

Development of the ADRs involves a consultative process within committees of the Australian Transport Advisory Council. The Council is made up of the State and Territory Ministers responsible for Transport.

The Vehicle Standards Advisory Committee and the Advisory Committee on Vehicle Emissions and Noise have responsibilities for the safety and environmental Design Rules respectively.

These committees consist of representatives from Federal, State and Territory governments, industry, consumer groups and vehicle safety experts.

Draft ADRs are circulated widely for 90 day public comment before they are finalised.

1.1.2 Certification of Vehicles

Manufacturers seeking Compliance Plate Approval need to assure the Administrator within the Federal Office of Road Safety that the model for which certification is sought has been tested in accordance with ADR requirements and that it complies with all applicable ADRs.

Demonstration of compliance is by way of submission of key details of tests and design for the various ADRs which are applicable to a particular category of vehicle.

These are submitted on "Summary of Evidence" Reports which are prepared from original test reports.

After these are examined and shown to meet the technical requirements of the ADRs, the Administrator issues an approval to the manufacturer which allows the fitment of a Compliance Plate to vehicles of that type. This plate shows that the vehicle meets the ADRs which are applicable to it.

The presence of a Compliance Plate on a vehicle is taken as proof by State and Territory registration authorities that the particular vehicle complies with the ADRs.

An inspection is carried out on a single example of a new model before it goes on sale. This is known as a Single Uniform Type Inspection (2) and visually checks that the vehicle "type" meets the various safety requirements set out in the ADRs. This inspection is a prerequisite for "bulk registration" of new vehicles.

1.1.3 Audit of Testing Facilities and Vehicle Manufacturing Plants

Test Facility Inspections assess a test facility's fitness to test to ADR requirements together with the witnessing of tests as opportunity occurs. These assessments are done by examining the capability of the personnel, equipment and procedures to properly conduct ADR testing.

During a Test Facility Inspection, original test reports from which Summary of Evidence Reports have been prepared are selected for detailed examination. As an aid in implementing and managing test facility inspections, a Test Facility Inspection Manual (3) has been produced. The procedures provide an indication of minimum standards and test methods. Alternative test procedures may be used to carry out the tests provided they meet the same standards.

Conformity of Production assessments of vehicle manufacturers' production facilities involve auditing of the production process to confirm that the company has systems in place which ensure each vehicle produced is identical to the approved type. These assessments include review of the quality assurance, purchasing, process control and inspection systems.

A Conformity of Production Manual (4) has been prepared for the guidance of assessors and industry. It specifies how an assessment should be conducted and provides guidance on what features should be present in a properly controlled manufacturing system. The manual is based on Standards Australia and the International Standards Organisation standards on quality systems.

The interval between assessments is between 18 and 24 months and takes into account the inspection history of the facility, the volume of ADR testing and the associated vehicle numbers produced.

Vehicles which are manufactured overseas are treated in exactly the same way as Australian built vehicles. Agents have been commissioned to perform both these audits on our behalf where suitable expertise exists. The agents are audited on a regular basis to ensure that uniform assessment procedures are being followed in all assessments. Training courses are periodically conducted in Australia and overseas for both manufacturers and agents.

In countries where there are no suitable agencies, departmental officers carry out the work.

1.1.4 Safety Defects Investigation and Recall

Despite all the controls that manufacturers and Government's have in place, vehicles with safety defects can get out into the marketplace.

The Federal Office of Road Safety undertakes investigations into reports of alleged vehicle safety defects to determine if recall or other appropriate action by suppliers is necessary.

The reporting of alleged defects can come from varied sources — members of the public, consumer organisations, state authorities. FORS also have an information exchange program with the USA, Japan, Canada and the UK on safety investigations and recalls which has proved useful in determining whether or nor Australian specification vehicles are affected by an alleged defect.

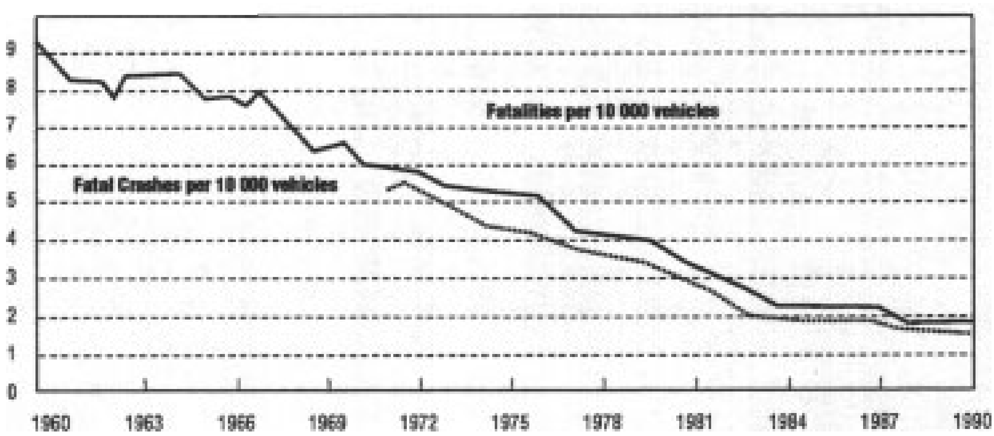
The automotive industry operates under a Recall Code of Practice. The majority of recalls are initiated by the vehicle manufacturers. The Trade Practices Act provides for compulsory recalls if manufacturers are unwilling to take action.

1.2 Achievements

Together with other Federal initiatives such as mandatory seat belt wearing and drink driving countermeasures, the ADRs have played an integral part in reducing road trauma.

The Figure 1 shows the reduction in fatalities since the first set of ADRs were introduced in 1969.

Figure 1
Road Fatalaties and fatal crashes per 10 000 vehicles, Australia, 1960–89



2 Current International Scene

There are effectively two bases for the assessment of occupant protection in passenger cars — the US approach (which is followed by Canada) and the rest of the world.

The US requirements are based on using instrumented dummies to measure surrogates for injury levels in frontal and side crash tests. The means by which the specified performance is achieved is left up to the individual manufacturer.

The rest of the world has, until now, specified the design requirements of individual components of the vehicle which may influence the likelihood of injuring the occupant in a crash. This approach may not necessarily result in the highest possible level of occupant protection in a crash.

The US methodology attempts to reproduce a more realistic representation of real life crash situations. There are attractions in "whole vehicle" performance assessment rather than component specification. However, the test dummies are very expensive and repeatability of the tests requires very tight control in the setting up stage.

2.1 Frontal Impact

The US approach specifies system performance rather than component design requirements for vehicles in frontal crashes. These requirements in Federal Motor Vehicle Safety Standard (FMVSS) 208 (5) predict the likelihood of injury to the head, chest and femur (upper leg) by the use of instrumented anthropomorphic dummies. FMVSS 208 tests are done at 30 mph (48 km/h).

The rest of the world, including Australia, currently adopts barrier crash test requirements which specify a limit to the rearward displacement of the steering column together with energy absorption requirement by the steering system (steering column and steering wheel). Tests are also done at 48 km/h.

The European (ECE) regulation has recently been amended to limit vertical column movement as well. It is anticipated that Australia will follow suit by amendment of Australian Design Rule 10/xx — Steering Column.

Other component design requirements for occupant protection cover such areas as seat and seat belt strength together with their anchorage points, interior padding etc.

There are indications in Japan and Europe of moves towards the US philosophy of specifying injury parameters measured by instrumented dummies.

2.1.1 Test Dummies

Currently, FMVSS 208 allows the option of using either a Hybrid II or Hybrid III dummy for compliance testing.

There are compelling arguments for using the latest available technology represented by the Hybrid III dummy. It better represents human responses (biofidelity) and has the capability of recording more injury data in the way of neck flexure, spinal behaviour, facial contact pressure, tibia and ankle loads, and abdomen injuries. Unfortunately, the current data base is not large enough to specify injury parameters for these additional body regions in a regulatory context.

Discussions are continuing in the international forums on further enhancements to dummy design to improve biofidelity. As these are still at an experimental stage, they are not appropriate for consideration in the context of regulation. The Hybrid III dummy is the state-of-the-art for regulation in the USA and Canada.

2.1.2 US Airbag

The FMVSS 208 requires the restraint system to protect the occupant whether the occupant choses to fasten the seat belt or not; the so called "passive restraint". This results in automatic seat belts with less than ideal geometry and large volume (60 to 70 litres) airbags now being fitted to an increasing proportion of passenger cars. These large airbags need to deploy early to protect the unrestrained occupant.

Because of this need for early deployment, the triggering controls need to be more sophisticated to ensure that false deployment does not occur during normal driving (travelling over railway lines, potholes etc). This also means more development crash testing to design the system.

Due to their large size and early deployment, fullsize airbags contain considerable energy when inflating. One concern has surfaced in relation to the injury caused in a small number of cases to occupants sitting very close to the airbag at the time of deployment.

2.1.3 Facebag or 'Eurobag'

A number of European countries have front seat belt wearing rates in the 70% to 80% mark. Although no regulations exist for mandating the fitment of an airbag, the more progressive European manufacturers are developing airbag systems using the Eurobag or facebag (30 to 35 litres).

This smaller airbag is designed to be used in conjunction with lap sash seat belts and is aimed at minimising injury to the head and upper torso.

Because of its higher firing threshold (as it is smaller and takes less time to inflate) it is less likely to fire inadvertently. Also because it is a less aggressive airbag it is less likely to cause injury in an 'out of position' deployment situation.

There is general agreement that the facebag can offer some degree of protection for an unrestrained occupant but may not meet the US FMVSS208 passive restraint requirements in particular vehicle models (ie for unrestrained occupants).

2.1.4 Offset Frontal Impact

A number of manufacturers claim that their vehicles have been designed to meet offset frontal crashes. The test procedures used by different manufacturers vary in the amount of overlap of the car structure to the barrier as well as inclination of the barrier face to the impacting car.

Currently, there are no regulations anywhere in the world specifying a test procedure for offset frontal crashes.

The European Experimental Vehicle Committee is proceeding with work to develop requirements for an offset frontal test procedure. The USA, Canada, Japan and Australia have been asked to participate so that a uniform test can be developed.

2.2 Side Impact

Currently, only Australia, Canada and the USA have regulations covering side impacts.

The Australian Design Rule 29 — Side Door Strength (1) is based on the original FMVSS 214 — Side Door Strength — Passenger Cars (6). This is a static crush test of the vehicle's doors.

The current US requirement is FMVSS 214 (same as ADR 29) except that vehicles not fitted with seat belts must meet a dynamic test in FMVSS 208 which specifies head and chest injury parameters.

A new version of FMVSS 214 with completely revised requirements has been introduced in the USA with a phase in starting September 1993. The test involves the stationary test vehicle being impacted at 54 km/h by a moving deformable barrier (mass 1360 kg). The intent of the standard is to replicate an intersection crash with the striking vehicle travelling at 48 km/h and the struck vehicle travelling at 24 km/h.

Chest and pelvic injury parameters are specified for two Side Impact Dummies, one of which is placed in each of the outboard front and rear seating positions on the impacted side.

A new European ECE Regulation is being finalised with a 1995 introduction date which allows a quasi-static composite test procedure to be used provided back-to-back tests proves this procedure correlates with the dynamic test. The test requires a deformable barrier (mass 950 kg) to impact the side of the test vehicle at 50 km/h.

There is still considerable debate over the US and European regulations which are similar in intent but different in a number of detailed areas. The main areas of debate are:

- the mass and characteristics of the deformable barrier face are different due to the different vehicle fleets in Europe and the USA
- the trolley is 'crabbed' in FMVSS 214 while the ECE regulation has it striking the test vehicle at right angles
- the test dummy
- the injury parameters

Research in Japan using the two test procedures indicates that they give different results.

Australia will be monitoring developments in this area with a view to adopting a uniform regulation for a dynamic side impact test. If no uniform regulation can be agreed upon, Australia will give consideration to accept testing to either European or American standards.

2.3 Rollover

The number of accidents in Europe involving rollovers is low. No legislation is currently being considered.

In the USA, the sales figures of light trucks are of a similar order to those of passenger cars. Accident statistics show that these light trucks are over-represented in rollover crashes compared to passenger cars. Because of this, the Americans are looking at a stability requirement for vehicles. The test method and applicable vehicle categories has not been finalised.

The dynamic rollover test in FMVSS 208 is acknowledged to have a number of deficiencies particularly in the area of repeatability. This is merely a test of occupant containment within the vehicle structure and no injury parameters are specified.

The static roof crush test in FMVSS 216 — Roof Crush Resistance — Passenger Cars (7) provides an indication of roof strength and addresses, in part, concentrated loads such as rocks, tree stumps etc.

It is generally agreed that the dynamics of a rollover are complex; with no two incidents being identical.

Australia's rollover accidents (15% of all fatalities) are more in line with the low levels in Europe particularly when allowance is made for fatalities due to ejection from the vehicle. Consequently, the development of a rollover has been accorded a lesser priority at this stage than frontal impact protection which is where the majority of deaths and injuries occur.

A recent survey conducted at the request of FORS by the Federal Chamber of Automotive Industries indicated that 95 percent of vehicle models sold in Australia have been designed to meet the US rollover standard, FMVSS 216. Based on this, the industry has been asked to consider introducing a code of practice on compliance with the American standard.

In addition, Australia will monitor developments in the USA for a new dynamic rollover test.

3 Occupant Protection Review Process

Passenger car design and construction have changed radically since the present Design Rules relating to occupant protection were formulated.

It became evident to the Federal Government that if it was to build on the achievements of reduced road trauma over the last few decades, it needed to look at ways of further enhancing occupant protection in passenger cars.

A $1 million standards development program was initiated to identify the causes of injuries to vehicle occupants in frontal crashes and to help develop a cost effective strategy to reduce these injuries.

3.1 Monash University Accident Research Centre Crashed Vehicle Study

To lay the foundations for this review, the Monash University Accident Research Centre (MUARC) was commissioned by FORS in 1989 to carry out a major study to determine how vehicles complying with the Design Rules were performing in real life crashes.

This study, "Passenger Cars and Occupant Injury" — FORS Report CR 95 (8), was released in April 1991 and focused on front seat occupants in frontal collisions as these are the most common type. The research was divided into three parts:

- A review of international safety literature to provide a background of the types of injuries being sustained by vehicle occupants, the sources of these injuries within the vehicle, and international developments in occupant protection.
- A detailed analysis of seven and one-half years of Transport Accident Commission injury compensation data involving occupants of late model vehicles, supplemented by police accident report details, to obtain an overview of the pattern of injuries to occupants of modern passengers cars in Australia.
- An in-depth study of 227 passenger car crashes in and around Melbourne where at least one occupant of a modern passenger car (post–1982) was hospitalised from the crash (total of 269 patients). This investigation involved an examination of patients and their vehicles to link occupant injuries with sources of injury inside the vehicle for various types and severities of crashes.

This study provided FORS with valuable information on the types and severity of injuries that people were sustaining, an indication of what had caused them and a range of possible countermeasures to address these injuries.

This work indicated that although Australia has one of the highest seat belt wearing rates in the front of passenger cars (94 percent) (8), occupants were still sustaining head, chest and leg injuries in crashes of the severity commensurate with current legislative requirements.

The study also showed that the proportion of persons killed or injured in a crash who were not wearing belts is higher (17%) than the proportion in the driving population as a whole (6%).

The MUARC crashed vehicle study (8) has been extended to provide more data on side impact crashes. This will assist in identifying the vehicle contact areas which are causing the injuries, and provide guidance for future work in this area.

3.2 Outline of Standards Development Program

The MUARC study analysed actual injuries in road crashes and related them to parts of the vehicle which caused them.

To move the analysis from real life crashes to tests of vehicles which give a consistent basis for evaluation, it was decided to conduct a series of barrier crash tests on a range of Australian produced vehicle models as a first phase. A test method was needed which would provide an indication of injury levels to the occupants in the crashed vehicle so that this could be related to the MUARC study of what was happening in real life crashes. The procedure needed to be an established standard which could be developed into an Australian Design Rule for frontal impact protection, if the program showed this was appropriate.

Therefore the first phase of the crash program used the procedures set out in US Federal Motor Vehicle Safety Standard 208 to test seven Australian produced vehicle models. These tests used state-of-the-art Hybrid III instrumented test dummies restrained in the front seating positions. The US regulation assesses performance by using established injury parameters recorded by the dummies during a crash test.

The second phase was to take some of the possible countermeasures identified in the MUARC crashed vehicle study (8), group them into three combinations and optimise their fitment into one of the vehicle models used in the first phase of testing. This was done using computer simulation and laboratory sled tests.

The third phase was to fit these components into actual vehicles for crash testing to get an indication of likely improvements in real life crashes.

To complement the crash test program, a study on the cost-effectiveness and feasibility of the various safety options was carried out.

In addition, a study was commissioned to examine the feasibility of conducting a consumer 'willingness to pay' survey for safety measures, and to develop a methodology to conduct such a survey.

FORS also took the opportunity to join in some laboratory tests (9) that the NSW Roads and Traffic Authority were conducting on a range of new safety technology.

In summary, the main elements of the FORS standards development program are as follows:

- Crash testing of seven Australian produced vehicles to provide baseline data
- Autoliv in Germany, a world leader in seat belt and airbag technology, to analyse the data to develop and provide enhanced safety systems to be used for further tests
- Three further crash tests on Australian cars fitted with these enhanced safety systems
- Monash University Accident Research Centre to study the cost effectiveness and feasibility of safety options
- A study of consumer willingness to pay for safety measures
- Laboratory tests on a range of new technologies to be undertaken by the NSW Roads and Traffic Authority

4 Crash Test Program

The crash test program, detailed in FORS Report OR 11 — Review of Passenger Car Occupant Protection, Crash Test Report (10), incorporated the following main elements:

- Crash testing of seven Australian produced vehicles to provide baseline data
- Autoliv in Germany, a world leader in seat belt and airbag technology, to analyse the data to develop and provide enhanced safety systems to be used for further tests
- Three further crash tests on one Australian model fitted with these enhanced safety systems

4.1 Test Procedure

The tests were conducted using the test procedures of the United States Federal Motor Vehicle Safety Standard 208 (FMVSS 208), with state-of-the-art 'Hybrid III' instrumented dummies restrained in the front seats by the vehicle's lap/sash seat belts. The full frontal crash tests were performed at a nominal impact speed of 48 km/h.

The following injury parameters were measured: Head Injury Criteria (HIC); Chest Deceleration; Chest Deflection; Femur (upper leg) loading. These parameters indicate the probability of injury to occupants in a crash of similar severity.

The barrier crash testing was conducted at the facilities of General Motors-Holden's Automotive Limited, which were leased after successful tender, under the supervision of FORS engineers.

Initial dummy calibration was performed by the dummy manufacturer, First Technology Safety Systems.

Dummy calibration was then performed before and after the test program and after each test by the NSW Roads and Traffic Authority's Crashlab.

4.2 Phase 1 — Baseline Crash Tests

The first phase of the Crash Test Program was conducted to provide base data on seven Australian production vehicles.

All test vehicles were selected at random from stock purchased through the Federal Government's fleet vehicle contract. The following vehicles were tested in Phase 1:

Ford EA Falcon GL Sedan
Ford Laser GL Hatchback
Holden VN Commodore Executive Sedan

Mitsubishi Magna TR Executive Sedan
Nissan Pintara Executive Sedan
Toyota Camry Executive Sedan
Toyota Corolla GL Hatchback

The tests indicated that the main difference in performance between the vehicles was in the area of HIC. The test to test variability in this type of complex test procedure can be significant, and the differences in design and configuration of the vehicle also has major effects on the test result. Evidence available from similar overseas testing indicates that test to test variability can be in the order of 20% or more.

There has been considerable debate overseas on HIC figures when using Hybrid III dummies when no head contact has occurred during the test. Research overseas suggests that a HIC calculation over a 15 millisecond time interval (HIC15) may be more appropriate when no head contact has occurred. Therefore, the HIC15 value has been reported as well as the HIC value calculated over the normal 36 millisecond time interval (HIC36).

Generally the HIC value was lower for the Passenger than for the Driver. Head contact with steering assembly, and also the instrument panel in the event of steering wheel deformation, is the likely reason for this observation. However, there was a heavy head strike on the instrument panel on the passenger side on one vehicle which produced a higher HIC than that recorded for the driver's position.

Passenger head contact with dashboard occurred in four of the vehicles.

For all vehicles the chest deceleration was greater for the Driver than for the Passenger. There was chest contact with the steering wheel in all cases.

The chest deflections of the Driver were generally greater than those of the Passenger. This is attributed to Driver contact with the steering wheel. There was one exception where the Passenger's value was marginally higher.

The femur loadings were usually lower for the Passenger than the Driver. This could be partially explained by passenger dummy leg contact with the glovebox lid which usually has an open cavity behind it.

While there were some injury levels near the threshold of a possible significant injury, none of the vehicles produced dummy responses which were considered life threatening. Table 4.1 summarises the FMVSS 208 injury criteria measured during the Phase 1 crash tests.

The Ford Laser was chosen for development of the enhanced restraint systems to be tested in Phase 3 as it was the highest selling small car. The smaller packaging providing designers more challenges in addressing occupant impact with the interior. In addition, it has adjustable upper seat belt mounts which gave some scope for changing the belt geometry. The

Phase 1 tests also showed that the belt loads were such as to provide scope for using buckle pretensioners and webbing clamps which tend to make the restraint system stiffer thus increasing the belt loads.

It is important to note that due to test to test variability, the Phase 1 test results from this program do not form a basis for drawing sustainable comparison of the safety performance of each vehicle.

Table 4.1
FORS Crash Test Program — Phase 1
Injury criteria results — 48km/h full frontal crash tests

Vehicle	BT225		BT228		BT234		BT235		BT236		BT237		BT238	
	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass
Head Injury Criteria (HIC36)	622	872	779	N/A	882	322	623	523	848	699	1012	860	820	#445
HIC15	594	832	547	N/A	759	143	433	282	848	645	719	841	716	258
Chest Decel (g)	58.5	41.7	54.0	50.8	46.8	46.3	46.7	41.1	47.7	46.2	59.4	48.5	47.5	43.4
Chest Deflection (mm)	49.0	38.9	41.9	36.7	38.7	33.1	41.4	29.2	36.6	39.1	42.7	29.1	46.1	30.0
Femur Loads (kN)														
Left Leg	2.14	2.01	2.34	1.22	1.03	1.28	15.40	1.76	3.30	1.55	4.20	1.81	1.13	1.48
Right Leg	1.78	0.91	2.07	1.16	3.60	1.46	3.38	3.10	1.88	2.06	6.80	2.93	9.47	1.43

Notes:
N/A — for BT228 does not contain the Passenger HIC, which was lost during the test. No head contact occurred.
— for BT238 uses the Y-axis deceleration of the driver in calculating passenger HIC (again due to instrument failure).

4.3 Phase 2 Restraint Optimisation

The second phase involved Autoliv in Germany, a world leader in seat belt and airbag technology, to analyse the data and develop the following three combinations of new restraint technology:

- Energy absorbing steering wheel, buckle pretensioners and webbing clamps.
- Driver's airbag and standard restraint system.
- Driver's airbag, buckle pretensioners and webbing clamps.

Development work began with analysis of the baseline data for the Ford Laser together with input of characteristics of components likely to influence the kinematics of the occupant in a crash. This included component stiffness measurements where occupant contact occurred during test.

This information was analysed using a computer model (MADYMO 2D) to firstly examine correlation between the model and the actual crash test in Phase 1. Once this correlation was established simulation runs were conducted to analyse the effect on dummy kinematics of the individual devices. Further modelling was then carried out to develop the three enhanced safety systems mentioned above. The results of this work are given in Tables 4.2 and 4.3 supplied by Autoliv.

Following completion of the computer simulation, the systems were fitted to a vehicle body shell for validation of the computer predictions on a sled simulating a full frontal crash at 48 km/h. The results are given in Table 4.4 supplied by Autoliv.

It should be remembered that the Phase 2 work done by Autoliv to develop the enhanced safety systems was tailored to meet the objectives of the research program and the fact that no structural changes could be made especially in the areas of seat belt geometry and seat design.

Autoliv note that the crash event analysed is only one of a multiple of variations in crash conditions which can create different occupant kinematics relative to the vehicle compartment. This can in turn modify the effects of the system components described.

Autoliv also note that the components tested have been optimised to a certain point but have not been optimised to the level appropriate for a production vehicle. A further development program would be necessary before introduction into the marketplace.

A complete pre-production optimisation program would take these factors into consideration as well as the other crash situations outside any legislative requirements.

This work demonstrates, primarily, the potential for improving occupant protection by incorporating various components. Care should be taken when considering the absolute values of injury criteria quoted when relating them to actual crash conditions.

Table 4.2
FORS Crash Test Program — Phase 2
Computer simulation — driver side results

	Grabber	Pretensioner	Eurobag
Run			
1	-	-	-
2	+	-	-
3	-	+	-
4	-	-	+
5	+	+	-
6	+	-	+
7	-	+	+
8	+	+	+

Run	1	2	3	4	5	6	7	8
Head								
HIC 36	1039	1241	1093	653	1241	641	612	625
t1 - t2 [ms]	74 - 104	72 - 106	78 - 107	69 - 105	81 - 99	69 - 105	68 - 104	67 - 103
HIC 15	823	989	745	326	1196	314	318	371
t1 - t2 [ms]	81 - 95	81 - 96	80 - 95	87 - 102	81 - 96	79 - 94	77 - 92	76 - 91
3 ms [g]	75	87	67	56	100	54	54	59
Chest								
3 ms [g]	54	50	46	43	45	45	43	43
Deflection [mm]	43	45	43	39	43	38	35	37
Pelvis								
Max. acc. [g]	75	75	70	75	69	74	71	68
Femur Load								
Force [KN] L + R	8,9	7,7	4,5	8,4	4,1	7,1	4,4	4,1

Table 4.3

FORS Crash Test Program — Phase 2
Computer simulation — passenger side results

Run	1	2	3	4
Head				
HIC 36	1128	957	903	841
t1 - t2 [ms]	76 - 107	75 - 110	75 - 110	74 - 110
HIC 15	880	531	596	502
t1 - t2 [ms]	88 - 102	82 - 97	88 - 103	83 - 98
3 ms [g]	90	68	70	67
Chest				
3 ms [g]	47	48	45	46
Deflection [mm]	41	44	40	42
Pelvis				
Max. acc. [g]	67	65	66	64
Femur Load				
Force [KN] L + R	4,4	4,1	3,8	3,6

Table 4.4
FORS Crash Test Program — Phase 2
Summary of sled test results

Testnumber	Stand. Belt	Grabber	Pretensioner	Soft Steering Wheel	Eurobag	Sled [g]	Head res. max. [g]	Head Resultant HIC 36	Head Resultant HIC 15	Head a_{3ms} [g]	Chest res. max. [g]	Chest res. a_{3ms} [g]	Chest Deflection [mm]	Pelvis res. max. [g]	Shoulder belt outer [kN]	Lapbelt outer [kN]	Femur load left [kN]	Femur load right [kN]	Bag Pressure [kPa]	Belt reel out [mm]	Result
Passenger																					
Crash	X							860	841	120	48,5	45	29,1		6,8	11,0	1,8	2,9			
X00B0001	X					29	132	690	528	74	44	43	34	53	7,2	8,0	1,6	5,0	---	---	i.o.
X00B0002	X					35	125	456	406	89	54	52	30,2	79	6,9	10,2	2,9	3,7	---	---	Seatscrew on buckle-side torn
X00B0004		X				35	120	283	272	58	56	54	33	54	8,0	11	---	---	---	---	Height adjuster torn
X00B0006		X				34	68	684	452	66	69	65	41,8	60	11,1	12,6	---	---	---	18	i.o.
X00B0007		X	X			29	69	789	451	67	56	52	44	56	10,4	10,1	1,9	2,1	---	14	i.o.
Driver																					
Driver	X							1012	719	86,0	63	59	43		7,0	8,0	4,2	6,8			
X00B0003	X					35	210	568	507	73	68	66	56	99	7,6	6,7	5,6	10,4	---	---	i.o.
X00B0005		X		X		34	88	624	578	78	57	54	32,5	109	9,8	9,6	5,4	7,2	---	---	Seatscrew on buckle-side torn
X00B0008		X	X	X		30	92	858	741	86	53	51	35,7	81	10,8	8,5	3,1	5,6	---	19	i.o.
X00B0009		X	X		X	30	69	595	482	68	58	55	37,1	83	11,3	8,3	2,4	6,3	117	22	i.o.
X00B0010	X				X	36	74	557	520	70	84	71	35,6	107	7,7	6,9	7,5	11,0	112	42	i.o.
X00B0011		X		X		35	78	716	665	75	62	60	36.4	83	10.9	10.5	2,4	3,6	---	20	i.o.

4.4 Phase 3 — Crash Tests on Vehicles Fitted with Improved Restraints

The third phase was the crash testing of three more vehicles fitted with the enhanced safety systems using prototype components developed in Phase 2 for a full frontal impact at 48 km/h.

The three Phase 3 test vehicles were again selected at random from stock purchased through the Federal Government's fleet vehicle contract.

The results showed that both the airbag and TRRL energy absorbing steering wheel (11) were effective in significantly reducing the driver HIC.

The test also showed that the buckle pretensioner and webbing clamp were effective in reducing forward excursion of the occupants. This had the effect of reducing both the HIC and chest deceleration and chest deflection.

The buckle pretensioner was effective in reducing femur loads in that toepan intrusion was the major cause of leg loading in tests where this device was fitted. In the baseline test with the standard restraint system, instrument panel intrusion was responsible for the higher maximum femur loads.

The results of the Phase 3 crash tests are given in Table 4.5.

Table 4.5

FORS Crash Test Program — Phase 3
Injury criteria results with different restraint systems for 48km/h full frontal barrier crash tests

Test Vehicle	BT 252 TRRL/WC PT		BT 253 Airbag/std restraint		BT 258 Airbag/WC PT	
	Driv	Pass	Driv	Pass	Driv	Pass
Head Injury Criteria (HIC 36)	598	408*	553	871	547	661*
Head Injury Criteria (HIC 15)	484	253	402	741	424	338
Chest Decel (g)- 3msec	39	40	57	48	42	42
Chest Deflection (mm)	34.4	34.0	40.0	31.4	39.9	N/A#
Femur Loads (kN)						
Left Leg	2.0	1.5	3.6	1.9	N/A#	2.6
Right Leg	4.3	2.4	8.4	3.2	N/A#	2.3

* No head contact
\# Data corrupted and unrecoverable
TRRL Energy absorbing steering wheel developed by UK Transport and Road Research Laboratory
WC Webbing clamp retractor with 7% elongation webbing
PT Seat belt buckle pretensioner

4.5 Discussion

It is important to note that due to test to test variability, the Phase 1 test results from this program do not form a basis for drawing valid comparison of the safety performance of individual vehicles. This test to test variability can be in the order of 20% or more. However, the test results provided objective information on the general level of performance of the Australian fleet.

It should also be noted that because of the differences in restraint systems and positioning of hardware in left hand vehicles, a model complying with the US regulations may not necessarily do so when tested in a right hand drive configuration; the technology is not necessarily simple to transfer.

It is important to bear in mind that the Phase 2 work done by Autoliv to develop the enhanced safety systems was tailored to meet the objectives of the research program and the fact that no structural changes could be made especially in the areas of seat belt geometry and seat design. A complete optimisation program would take these factors into consideration as well as the other crash types (into poles, offset frontal etc) outside the legislative requirements.

The Phase 3 crash tests were performed to confirm the potential for injury reduction indicated by the Phase 2 work.

The Phase 3 vehicles demonstrated one aspect of test variability in that, although they were consecutive build cars, they all exhibited different crash pulses.

The strategy to achieve improvements in occupant protection should be developed in the context that there are uniform compulsory seat belt regulations in Australia, with a wearing rate of over 90% in front seats.

4.6 Outcome of the Crash Test Program

The vehicle models used in the Phase 1 crash tests were built to conform to the current Australian Design Rules for vehicle safety and provided a level of safety comparable to that offered by equivalent vehicles in Europe and Japan. There were no unexpected structural failures observed during the crash tests.

The work done by Autoliv in Phase 2 (restraint optimisation) showed that individual components when used in isolation sometimes resulted in an increase in injury levels. The development work to optimise the restraint system for a particular vehicle is necessary to ensure that the various components used in combination will result in an improvement in the level of occupant protection provided.

The outcome of the Phase 3 crash tests showed that there were significant improvements possible with the range of emerging technology when properly engineered into a vehicle.

The crash test program has shown that improvements in occupant protection could be achieved through the implementation of a new Australian Design Rule for frontal impact protection which sets performance requirements based on the established injury parameters in US Federal Motor Vehicle Safety Standard 208.

The crash test program also demonstrated that considerable development work would be required to achieve performance levels high enough to give manufacturers confidence that production vehicles would meet the requirements of a regulatory regime based on the American standard.

In summary, the crash test program confirmed that an Australian Design based on FMVSS 208 injury criteria would lead to significant improvements in occupant protection and would bring about the fitment of a range of emerging safety technology.

5 Laboratory tests on emerging safety technology

The Federal Office of Road Safety collaborated in a research project conducted by the NSW Roads and Traffic Authority's Crashlab and the US National Highway Traffic Safety Administration on laboratory sled tests to evaluate emerging safety technology.

At the instigation of FORS, the energy absorbing steering wheel developed by the UK Transport and Road Research Laboratory (TRRL) (11) was added to the list of components to be evaluated.

5.1 Project Objectives

The test program was conducted in three stages and utilised part of an actual vehicle body shell mounted on a sled to represent the total vehicle restraint environment.

The aim of the first stage was to develop expertise with the Hybrid III test dummy and to validate the test methods and procedures to be used throughout the entire project. The Stage 1 tests also established the base line performance of the standard lap sash retractable seat belt in the test configuration and investigated the effects of the upper torso anchorage point location and seat cushion stiffness on dummy kinematics. The work of the first stage is detailed in Crashlab Special Report SR90/183, "Occupant Restraint Project — Report on Stage 1" (9).

The aim of Stage 2 was to obtain representative samples of new technology restraint systems and/or components and to conduct an objective evaluation of their influence, when used in isolation, on the performance of the standard lap/sash retractable seat belt. This work is reported in Crashlab Research Note 4/91, "Occupant Restraint Technology Evaluation — Report on Stage 2" (9).

The main aims of Stage 3 were to evaluate the base line performance of the TRRL energy absorbing steering wheel, and to evaluate the compound performance provided by a combination of new restraint technology. This work is reported in Crashlab Research Note 3/92, "Occupant Restraint Technology Evaluation — Report on Stage 3" (9).

5.2 Test Method

The tests were performed on the Crashlab MTS Monterey Crash Simulator. This sled produces the required impact velocity by the rebound principle using an opposing force gas cylinder (programmer) to produce the required impact acceleration pulse which is basically a half sine wave.

The test buck was composed of a full width body section from the firewall to the B-pillar, reinforced at load points. The doors and roof sheet panels were removed to facilitate high speed photography and the windscreen was replaced with polycarbonate sheeting.

The steering wheel and column assembly were retained in production configuration except for the removal of cosmetic trim. The dash board crash pad and facia trim were retained.

A production model bucket seat was used in all of the tests. The metal seat base frame was replaced after every run and the entire seat base assembly was replaced after every second run. The seat squab and recliner mechanism were replaced as required if damaged during a test.

The test procedures specified in FMVSS 208 were followed within the bounds of applicability for sled testing noting the following points:

- Seat runners were replaced with a rigid mounting frame to ensure consistency from test to test. The frame represented the seat positioning specified in FMVSS 208 (mid point of adjustment or the first engagement position rearward of it).
- In the absence of specific information for the vehicle, the standard default seat back angle of 25 degrees was used.
- The steering column which was adjustable for reach and rake was positioned in the outermost (reach) and uppermost (rake) position to present the worse case situation for head strike. FMVSS 208 specifies the mid point of the locus prescribed by the available adjustment (ie the mid point of reach and rake).

Tests were performed in the driver's seating position only. A Hybrid III dummy was used for all tests.

Two sets of tests were performed using two levels of deceleration pulse which corresponded to the minimum and maximum pulses which met the requirements set out in ADR 4/..:

- a velocity change of not less than 49 km/h
- a deceleration in the range 235 to 335 m/s/s with a rise time of less than 30 milliseconds
- deceleration level maintained for not less than 20 milliseconds, except for periods of less than one millisecond.

This gave a minimum pulse of about 24g average with a peak of about 28g. The maximum pulse peaked at about 34g with an average of about 30g.

Two tests were conducted for each restraint combination at each of the two deceleration levels.

The Injury Assessment Values (Mertz) (12) used were those for:

- resultant head acceleration (HIC)

- resultant thoracic spine acceleration
- compression deflection of the sternum
- axial force transmitted through each upper leg
- neck bending moment
- axial neck loads
- neck shear force.

The first four are the injury criteria specified in FMVSS 208 and the remaining three are specified in Mertz.

5.3 Evaluation of New Safety Items in Isolation

The following devices were tested in the second stage of the program to isolate their effects on the performance of the standard 'base line' lap sash seat belt:

fullsize airbag (70 litres)
TRRL steering wheel
tongue clamp
low elongation webbing
buckle pretensioner
static belt
retractor mounted webbing clamp

The test results demonstrated that each device performed as it was designed to, at the component level. For example, the tongue clamp improved the overall pelvic restraint and the retractor webbing clamp reduced spool out by up to 80%.

However, these sled tests showed that the various components when used individually did not improve the injury values produced. The exceptions were the airbag and the TRRL steering wheel, and even then only in some injury criteria.

The trend that emerged was that the components which modified the seat belt assemblies (webbing clamp, buckle pretensioner) changed the dummy kinematics by lowering the initial impact site of the head with the steering assembly. This resulted in a heavy head strike with the steering wheel hub which produced high HIC values when using the standard production wheel.

The test results highlight the significance of the interaction between the different components of the total vehicle restraint system such as the effects of seat location, cushion stiffness, steering wheel position and seat belt performance. When variations in physical stature and preferred driving position are also considered, the complexity of effectively optimising a restraint system becomes apparent.

5.4 Evaluation of New Safety Items in Combination

The main objective of Stage 3 was to evaluate the compound effect of using the new technology restraint devices in combination with one another.

The testing of the TRRL steering wheels was also done at this time because they were not available when the remainder of the Stage 2 work was performed. The results of these tests are discussed in Section 5.3.

To look at the compound effect of restraint devices in combination, a restraint system incorporating a retractor webbing clamp and buckle pretensioner was used in conjunction with the TRRL wheel, a standard production wheel and a superseded wheel design. Based on the Stage 2 testing, these restraint changes would promote a hub strike. This is the area where the TRRL wheel has the highest injury mitigation potential.

The results obtained in this third stage indicate that significant contributions to head injury mitigation can be made through steering wheel design, although energy absorbing steering wheels on their own may not lead to significant reductions in injury at higher speeds.

The TRRL wheel performed significantly better than the production wheel in relation to HIC when used in conjunction with a buckle pretensioner and retractor webbing clamp which changed the head trajectory to promote a head strike on the hub.

5.5 Discussion

It should be remembered that these series of tests were conducted to provide an indication of the performance benefits available from the range of new safety restraint items.

Although only tests on the driver's side were performed, the modified seat belt assembly components had the potential to improve occupant protection in the passenger's position through the reduction in forward excursion.

The results should not be used for direct comparison of the components tested because there are variables which can affect real life restraint system response which are difficult to replicate in sled testing. These include the dynamic effects of the interior components eg steering wheel and column assembly, dashboard, toepan intrusion etc. In addition, the actual vehicle crash pulse can vary between different models and drive train configurations and may be difficult to totally replicate in a sled test.

5.6 Outcome of Laboratory Tests on Emerging Safety Technology

The test results demonstrated that each of the devices tested performed as it was designed to, at the component level. For example, the tongue clamp improved the overall pelvic restraint and the retractor webbing clamp reduced spool out by up to 80%.

These sled tests, which seek to simulate a frontal impact, showed that components which modified the seat belt assemblies (webbing clamp, buckle pretensioner) did not show improved injury values when used in isolation. The addition of these components changed the dummy kinematics by lowering the initial impact site of the head with the steering assembly. This resulted in a heavy head strike with the steering wheel hub which produced high HIC values when using the standard production wheel.

The airbag and the TRRL steering wheel when used in isolation did show reduced injury levels, but even then only in some areas.

The third stage examined the effect of components in combination. The results showed that when used in conjunction with a buckle pretensioner and retractor webbing clamp which changed the head trajectory to promote a head strike on the hub, the TRRL energy absorbing steering wheel performed significantly better than the production wheel in relation to HIC. This was because the TRRL wheel has the greatest injury mitigation potential in the hub area.

This work highlighted the significance of the interaction between the different components of the total vehicle restraint system, namely, the effects of seat location, cushion stiffness, steering wheel position and seat belt performance. When variations in physical stature and preferred driving position are also considered, the complexity in effectively optimising a restraint system becomes apparent.

6 Feasibility Study of Occupant Protection Measures

This study provides a cost-benefit analysis of a range of vehicle safety measures recommended in the Federal Office of Road Safety's crash vehicle study "Passenger Cars and Occupant Injury CR 95 (8) on passenger cars and occupant injuries. It aimed to identify the most cost beneficial mix of countermeasures as a sound basis for policy decisions in developing future Australian Design Rules for frontal impact protection.

The details of this study are given in FORS Report CR 100, "Feasibility of Occupant Protection Measures" (13). The study was conducted by a consortium comprising of the Monash University Accident Research Centre, Ernst and Young and Kennerley Digges and Associates.

6.1 Countermeasures and Packages

One of the earlier tasks undertaken in the feasibility study was to evaluate the suitability of the full range of countermeasures listed in CR 95 (8).

Based on the latest available test results in international literature and recent developments overseas, the following list was considered in the study:

- seat belt pretensioners
- webbing clamps
- improved restraint geometry
  - improved buckle positioning
  - anti-submarining seat cushion
  - outboard lap anchorage positioning
- seat belt warning system
- full size US airbag
- supplementary facebag (Eurobag)
- energy-absorbing (padded) steering wheels
- limiting vertical and lateral steering column movements
- reduced instrument panel and toepan intrusion
  - knee bolsters
  - improved padding.

6.2 Industry Plans

Discussions were arranged with the Federal Chamber of Automotive Industries and with individual vehicle manufacturers to undertake an assessment of likely lead times and any potential difficulties for the possible introduction of the countermeasures being considered.

Information was also gained from overseas sources regarding lead times.

Lead times and difficulties in fitting a particular device can vary depending on whether a new model is being developed to incorporate particular countermeasures. Indeed, the redesign to fit some features into an existing model may be prohibitive. Table 6.1 taken from the MUARC report (13) summarises the estimated lead times.

Table 6.1

Comparison of lead times for introduction of various countermeasures

Countermeasure	FCAI position*1	Consultants assessments	
Seat belt pretensioners	36 months min	24 mths or less	*2*5
Seat belt webbing clamps	36 months min	18 mths or less	*2*4
Improved seat belt geometry	36 months min	18 mths or less	*3*5
Anti-submarining seat cushion	36 months min	18 mths or less	*5
Seat belt interlocks	no advice	18 mths or less	*6
Supplemental restraint system			
– US type Driver Side airbag	48 months min	32 months	*7
– US type Pass. Side airbag	60 months min	32 months	*7
– Euro type Drivers Side	48 months min	32 months	*7
– Euro type Pass. Side	no advice		
Padded steering wheels	no advice	28 months	*8
Improved padding upper areas	no advice	12 months	*9
Reduced instrument panel intrusions	36 months min	n.a.	
Improved instrument panel materials	no advice	n.a.	
Improved padding of lower areas	36 months min	n.a.	
Knee bolsters	no advice	n.a.	
Reduced intrusion	no advice	n.a.	
Adoption of US Standard FMVSS 208	36 months min	n.a.	

*1 FCAI have based minimum lead times generally on the introduction of a new model
*2 may be reduced if modifications to vehicle are not required (industry sources). This assumes no further engineering of the system or vehicle equipment (eg. steering wheel) to optimise with other elements of the restraint system.
*3 generally will require seat re-design
*4 modifications to B pillar likely to be required
*5 major seat redesign likely to be required
*6 will depend on type selected
*7 may be reduced if a system is already available in LHD configuration (industry sources)
*8 information provided to NHTSA
*9 information provided to NHTSA

Source: FORS Report CR 100, 'Feasibility of Occupant Protection Measures' — Monash University Accident Research Centre.

6.3 Costs of Countermeasures

A range of information was utilised in developing the assessment of likely costs of the countermeasures for the Australian market. These included:

- Information supplied by individual Australian motor manufacturers covering most of the countermeasures.
- International retail price comparisons such as those provided on airbags by the US National Highway Traffic Safety Administration (NHTSA) and the US Insurance Institute for Highway Safety.
- Information from local and overseas component manufacturers (adjusted for the Australian market) for a number of countermeasures.

For devices where no costs were available, cost estimates were compiled from first principles using the experience of the team members and subsequently adjusted after discussions with people within the vehicle industry.

As was the case with lead times, the costs associated with incorporating countermeasures into a vehicle will depend on a number of factors which will vary from model to model. These include whether the vehicle has been designed from inception to incorporate these components, whether that model is available overseas in the same specification and the amount of development, redesign and retooling work required.

Ranges of costs were provided when particular measures were seen to be sensitive to volume. In some instances, these ranges were then adjusted into a single figure taking into account weighting derived from current sales volumes.

In some cases, the cost of a countermeasure will depend on the design of the component. A mechanical pretensioner will have a different cost to a pyrotechnic pretensioner. An airbag with a mechanical triggering device will be cheaper than one with an electro-mechanical one, which in turn is cheaper than one with a full electronic triggering device.

Table 6.2 taken from the MUARC report (13) summarises the derived costs for the various countermeasures.

Table 6.2
Estimated retail price* of measures to new car buyers

Countermeasure	Industry estimates $	Est. best retail price for plan producer (New model) $
seat belt pretensioners	140, 150–190, 230	100–140*[1]
seat belt webbing clamps	30, 85, 100–130, 150	15 basic 50 deluxe
improved seat belt geometry	25	marginal, say $10
anti-submarine seat cushions	27, 35–45	marginal, say $10
seat belt warning system	50–80	20 basic 35 deluxe
supplementary restraint system — Fullsize driver airbag	500*[2]–1500*[3], 1000–1500, 1000–2000,	528*[9] – 800*[3]
supplementary restraint system — Fullsize passenger airbag	1800*[4], 2200*[5], 2500*[6] 470*[5], 1000–1500, 1400	528*[9] extra
supplementary restraint system —Fullsize airbag system [driver and passenger]	1500*[7]–3000*[3], 2700, 3200	1156*[9]
supplementary restraint system —Driver facebag	500 plus	478*[9]
supplementary restraint system —Passenger facebag	n/a*[8]	
Padded steering wheel	n/a	5–25
Improved padding upper areas	n/a	70–100
Reduced panel intrusions	n/a	0–30
Improved panel materials	n/a	zero
Improved padding lower areas	n/a	0–60
Knee bolsters	n/a	50–75
Reduced intrusions	n/a	u/k
Compliance with FMVSS208	760	u/k

* 1991 prices and exchange rates.

NOTES:
1. Retail price allowance of $40 has been made for vehicle modification. In a new model, this may not be appropriate as seat may be designed to accommodate pretensioners. Then, the likely retail price would be $100
2. Single-sensor mechanical control system.
3. Multi-sensor electronic control system
4. US airbag with multi-sensor electronic system
5. Based on adaptation of US system to a passive restraint system for Australian conditions. Passenger side bag shown as an additional cost to the driver side bag.
6. US specification from a European manufacturer
7. Basic mechanical control system
8. Industry estimates not available
9. For locally produced vehicles corresponding to an annual volume of the weighted mean for 8 plan production models.

Source: FORS Report CR 100, 'Feasibility of Occupant Protection Measures' — Monash University Accident Research Centre.

6.4 Injury Costs

An Australia-wide database was necessary to assess the likely injury reductions for each countermeasure. The Crashed Vehicle file from CR95 (8) offered the most appropriate source of data for this purpose since it contained both injuries and their contact source.

This data was converted into national statistics by adjusting the Crashed Vehicle file to take into account national accident frequencies and injury levels. This assumed that the adjusted injury levels were derived from similar sources of injury to those observed initially.

The average cost for each specific injury was estimated based on a matrix of average injury costs in the USA developed by Miller (1991). This provided a matrix of injury costs for various body regions for different injury severity (AIS 1 to 6).

Total costs of injuries for the various body regions for different injury severity was then obtained by multiplying the injury cost by the accident frequency in all types of impact.

These costs were then disaggregated into those for front seat occupants of passenger cars, both restrained and unrestrained, in frontal impacts.

The costs were further disaggregated into a matrix of body region against contact source based on information from the Crashed Vehicle file (8).

6.5 Estimates of Countermeasure Benefits

This chapter describes the means by which the likely benefits of the various countermeasures were estimated. This study used the "Harm" approach for assessing injury mitigation to calculate benefits.

The concept of "Harm" was first developed in the USA and applied to the National Accident sampling System (NASS) database by NHTSA as a means of determining countermeasure benefits for road safety programs. "Harm" refers to the annual cost of injury involving both incidence and treatment costs to the community.

Injury mitigation was estimated for each countermeasure from safety performance results which had been published in international road safety literature. Where performance results were unknown, best estimates of the likely improvements were made by an expert panel.

Australian "Harm" reduction figures were then determined for the various countermeasures using the disaggregated matrices on injury costs.

"Harm" calculations included the benefits to be derived from airbags for the small proportion of front seat occupants in Australia who do not wear seat belts (6%). The proportion of persons killed or injured who were not wearing belts in a crash is higher (17%) than the proportion in the driving population as a whole. Belted occupants account for most of the total "Harm" reductions estimated for airbags (77%).

6.6 Benefit-Cost Calculations

The Discounted Present Value method was applied to establish unit benefits for each countermeasure. While a 7% discount rate (as recommended by the Commonwealth Treasury) was adopted for these calculations, sensitivity analysis for a 4% discount rate was also performed. The lower discount rate gives greater weight to benefits received in the distant future. However, the lower rate also increases the cost of injury overall.

In calculating costs of each countermeasure, the "economic cost" was used, viz the estimated retail price minus sales tax and duty.

Benefit Cost Ratios (BCRs) were then derived for each measure. Tables 6.3 and 6.4 taken from the MUARC report (13) summarise this.

To give a broad base for assessment, Net Present Worth and the percent of annual trauma saved were also calculated for each measure.

6.7 Discussion

The authors claim that the information used in deriving the BCRs for the various countermeasures result in conservative estimates.

The occupant trauma reduction quoted is for an equilibrium situation where the whole vehicle fleet has a particular countermeasure or group of countermeasures. Considering the current age of the Australian passenger car fleet, this may take over ten years.

It should be noted that 'lifetime' costs of each measure, such as replacement and maintenance costs, have not been taken into account in the benefit-cost calculations. In addition, the fact that some countermeasures when used in isolation may increase injury has not been considered.

6.8 Outcome of the Feasibility Study of Occupant Protection Measures

To examine the likely benefits of countermeasures in combination, three packages were examined in terms of their economic worth and injury mitigation potential.

It was found that these packages, which incorporate the components tested in the FORS crash test program, were cost beneficial and had the potential of reducing vehicle occupant trauma from between 17% and 25%. This information is summarised in Table 6.5 which taken from the MUARC report (13).

Table 6.3
Cost and benefit summary for airbags and facebags

Item	Manufacturer's Costs	Best Estimate Retail Prce	Economic Cost (1)	Unit Harm(2) ($s per car)	Likely BCR Outcome
Fullsize Driver Airbag (Electronic sensors)	$500–$2500 (3)	$800 approx (4)	$665 approx	$515	0.77
Fullsize Driver Airbag (Electro-mechanical sensors)	$500–$2500 (3)	$528(5)	$440	$508(8)	1.15
Fullsize Passenger Airbag (in conjunction with driver airbag) (Electro-mechanical sensors)	$500 plus (7)	$528 (5)	$440	$80	0.18
Driver Facebag — Maximum Benefits (Electro-mechanical sensors)	$470–$3200 (6)	$478 (5)	$400	$391	0.98
Driver Facebag Minimum Benefits (Electro-mechanical sensors)	$470–$3200 (6)	$478 (5)	$400	$230	0.58

Notes:

1. Economic costs equals Ernst & Young's estimate of consumer cost minus sales tax and less duty on any imported items
2. Harm reduction is the estimated safety benefit per vehicle over its life (discounted to present day values)
3. Various control systems used varying from simple to multi-sensors involving mechanical, electronic or electro-mech.
4. Electronic control multi-sensor systems could add up to $250 (Ernst & Young Consultants)
5. Price based on a weighted mean of the eight plan production models using 1990 sales volumes listed in Paxus
6. Features of systems not specified
7. The additional cost of adding a passenger airbag to a driver airbag — features of the system not specifed
8. Harm mitigation reduced by 2% for the fullsize electro-mechanical airbag to account for occasional non-firing

Source: FORS Report CR 100, 'Feasibility of Occupant Protection Measures' — Monash University Accident Research Centre.

Table 6.4
Cost and benefit summary for non-airbag countermeasures

Item	Manufacturer's Costs	Best Estimate Retail Pice	Economic Cost (1)	Unit Harm (2) ($s per car)	Likely BCR Outcome
Seatbelt Pretensioner (seat)	$140–$230	$100–$140	$85–$115	$92	0.8–1.1
Seatbelt Pretensioner (shoulder)	n.a.	>$140	>$115	$53	0.5
Seatbelt Webbing Clamp	$30–$150	$15 (basic)–$50 (delux)	$12–$42	$42	1.1–3.5
Improved Belt Geometry & Seats	$50–$70	$ marginal ($10)	$ marginal ($8)	$58	7.3
Seatbelt Warning Device	$50–$80	$20 (basic)–$35 (delux)	$16–$28	$115	4.1–7.2
E-A Padded Wheel	n.a.	$5–$25	$4–$20	$64	3.2–16.0
Vertical & lateral Column Intrusions	n.a.	n.a.	n.a.	$62	unknown
Padded Upper Areas	n.a.	$70–$100	$60–$83	$25	0.3–0.4
Improved Lower Panels	n.a.	$6–$60	$5–$50	$90	1.8–18.0
Knee Bolsters	n.a.	$50–$75	$42–$62	$179	2.9–4.3
Reduced Floor & Toepan Intrusions	n.a.	n.a.	n.a.	$151	unknown

Notes:
1. Economic cost equals Ernst & Young's estimate of consumer cost minus sales tax and less any duty on any imported items
2. Harm reduction is the estimated safety benefit per vehicle over its life (discounted to present day values)

Source: FORS Report CR 100. 'Feasibility of Occupant Protection Measures' — Monash University Accident Research Centre.

Table 6.5
Countermeasure package BCRs, NPWs and % trauma saved

Countermeasure Packages	Economic Cost	Unit Harm Benefits	Likely BCR	Likely NPW	Vehicle Trauma Saved
Package 1 — Fullsize Airbag Fullsize Driver Airbag (electro-mechanical) Energy Absorbing Steering Wheel Seat Pretensioner (front Passenger only) Webbing Clamp (front Passenger only) Seatbelt Geometry & Seats Knee Bolsters	$543–$608	$858	1.4–1.6	$133–168 million	25%
Package 2 — Driver Facebag Driver Facebag (Minimum & Maximum Benefits) Energy Absorbing Steering Wheel Seat Pretensioner (front passenger only) Webbing Clamp (front passenger only) Seatbelt Geometry & seats Knee Bolsters Seatbelt Warning Device	$519–$596	$695Min $792 Max	1.2–1.3Min 1.3–1.5 Max	$53–94 million $105–146 million	20%Min 23% Max
Package 3 — No Airbag Energy Absorbing Steering Wheel Seat Pretensioner (front seat occupants) Webbing Clamp (front seat occupants) Knee Bolsters Seatbelt Warning Device	$165–$275	$568	2.1–3.4	$156–214 million	17%

Source: FORS Report CR 100. 'Feasibility of Occupant Protection Measures' — Monash University Accident Research Centre.

7 Consumer 'willingness to pay' for safety measures

The aim of the research project is to look firstly at the feasibility and methodology to conduct and analyse a survey on a sample of recent new car buyers to assess the community's 'willingness to pay' for improved *safety features in passenger cars.*

The second stage would be to pilot the developed questionnaire and then conduct the full survey and analyse the results.

7.1 First Stage — Feasibility Study and Methodology

This first stage was performed by Dwyer Leslie Pty Limited after successful tender. Details are given in FORS Report CR 102, "Willingness to Pay for Safety Features" (14).

The report recommends that 'Contingent Valuation' techniques be used as the best way to measure directly people's 'willingness to pay' for vehicle safety measures.

'Contingent Valuation' techniques have increasingly been used to estimate the value of unpriced public goods and for the provision of environmental services. The technique is particularly valuable where other methods such as analysis of market behaviour or direct data collection are precluded due to an absence of a market or available data.

'Contingent Valuation' studies are structured to describe a hypothetical market to an individual in a way that places that individual in an active role in the market — as a bidder for a specific outcome. The valuation questions request bids from individuals for stated changes in a carefully defined commodity. In effect, the person is confronted with the prospect of being able to purchase the change.

In this case, the commodity will be packages of safety measures set out in the Monash University Accident Research Centre's report CR 100 on the cost benefits of these packages. This will provide data on what the commodity is, what the outcome is (degree of injury mitigation), and what the cost is.

7.2 Survey Structure

To reduce the effect of any survey bias, it is suggested that the sample group be selected from people who have purchased a car recently, so that the decision making process is likely to be clearly remembered. It is suggested that purchasers of 12 to 18 months ago be used.

The two basic variants of the 'Contingent Valuation' technique which are proposed are 'take it or leave it' and 'bidding questions'. The fundamental reasons for choosing two variants of the technique is validation; the ability to cross check one set of results against the other. These two variants will act as an indicator for the reliability and validity of the results obtained.

For example, the 'take it or leave it' question would be the various packages in the MUARC report nominated with an approximation of their cost and injury mitigation potential. The 'bidding' question would be the same packages but the respondents would be asked how much they would be willing to pay for each.

Contextual background information will need to be provided together with a number of pre-conditioning questions. The main problem here will be that most of the safety items will not have been available on the car that was purchased, either optional or standard.

Face to face interviews will be required as the issues are too complex for a telephone survey or mail out.

The primary target group is recommended to be buyers of new, mass market family vehicles. Buyers will be grouped into both private and fleet purchasers. The buyers of luxury cars could be addressed as a smaller group. Vehicle groupings could be split up into either cost ranges from <$15,000 to >$35,000 or model ranges (small, medium, large).

Subject to privacy considerations, the easiest method of accessing buyers would be through vehicle manufacturers' customer service database.

A sample size of 500 is suggested, geographically separated as follows:

- Sydney, sample size 200
- Melbourne, sample size 200
- Canberra, sample size 100

A separate report on the second stage consisting of the survey and analysis of its results will be prepared so it can be considered in the decision making process.

8 Future research

The current work has focused on improving occupant protection in full frontal impacts.

Chapter 2 has pointed out the work currently in train overseas on offset frontal, side and rollover impact protection. Australia is also looking into these areas as well as restraint systems especially lap only belts and child restraints.

8.1 Offset Frontal Impact

Currently, there are no regulations anywhere in the world specifying a test procedure for offset frontal crashes.

Although some manufacturers claim that their vehicles have been designed to meet offset frontal crashes, the test procedures vary in the amount of overlap of the car structure to the barrier as well as inclination of the barrier face to the impacting car.

Australia has accepted an invitation to participate in the European Experimental Vehicle Committee which is proceeding with work to develop requirements for a global offset frontal test procedure.

8.2 Side Impact

Currently, only Australia and the USA have regulations in force covering side impacts.

The Australian Design Rule 29 — Side Door Strength is based on the original FMVSS 214 — Side Door Strength — Passenger Cars. This is a static crush test of the vehicle's doors.

A new version of FMVSS 214 with completely revised requirements has been introduced in the USA with a phase in starting September 1993. The intent of the standard is to replicate an intersection crash with the striking vehicle travelling at 48 km/h and the struck vehicle travelling at 24 km/h.

In Europe an ECE Regulation is being finalised with a 1995 introduction date which is also a dynamic test intended to replicate an intersection crash.

Unfortunately there is still considerable debate over the US and European regulations which are inherently different from the point of view of dummies used, type of deformable barrier, injury parameters etc.

Australia will be monitoring developments in this area with a view to adopting a uniform regulation for a dynamic side impact test. If this does not occur, Australia will give consideration to accept testing to both the European and American standards.

The Monash University Accident Research Centre crashed vehicle study (8) has been extended to provide more data on side impact crashes. This will assist in identifying the vehicle contact areas which are causing the injuries, and provide guidance for future work in this area.

8.3 Rollover

Rollovers are a much less frequent cause of death and injury in Australia than frontal crashes.

The same situation applies in Europe and no legislation is currently being considered.

In the USA, the sales figures of light trucks are of a similar order to those of passenger cars. Accident statistics show that these light trucks are over-represented in rollover crashes compared to passenger cars. Because of this, the Americans are looking at a stability requirement for vehicles. The test method and applicable vehicle categories has not been finalised.

A recent survey conducted at the request of FORS by the Federal Chamber of Automotive Industries indicated that 95 percent of vehicle models sold in Australia have been designed to meet the US rollover standard (FMVSS 216). Based on this, the industry has been asked to consider introducing a code of practice on compliance with the US regulation.

In addition, Australia will monitor developments in the USA for a new dynamic rollover test.

8.4 Restraint Systems

There has been increasing concern in recent years over the number of spinal injuries caused by lap only belts.

Future work will aim to examine this issue with the view to considering requirements for the installation of lap sash seat belts in all seating positions of passenger cars.

An improved ADR for child restraints has been endorsed under the Motor Vehicle Standards Act 1989 and will be introduced in 1993 which will facilitate the installation and interchangeability of child restraints in passenger cars. A second phase, to be introduced in 1994, will require the installation of an anchor fitting in the centre rear seating position to further facilitate the use of child restraints.

Work will continue to encourage, as much as possible, The integration of child restraint systems into the design of the vehicle.

9 Summary of Standards Development Process

The aim of this program was to identify the causes of injuries to passenger vehicle occupants in frontal crashes and to develop a cost effective strategy to reduce these injuries.

To lay the foundations for this work, the Monash University Accident Research Centre (MUARC) carried out a study to determine how vehicles complying with the Design Rules were performing in real life crashes.

This study, "Passenger Cars and Occupant Injury" — FORS Report CR 95 (8), was released in April 1991 and provided FORS with valuable information on the types and severity of injuries that people were sustaining, an indication of what had caused them and a range of possible countermeasures to address these injuries.

The MUARC study showed that occupants were sustaining head, chest and leg injuries in crashes of similar severity to the current ADR on barrier impact testing. The study also showed that the proportion of persons killed or injured in a crash who were not wearing belts is higher (17%) than the proportion in the driving population as a whole (6%).

To move the analysis from real life crashes to tests of vehicles which give a consistent basis for evaluation, it was decided to conduct a series of barrier crash tests on a range of Australian produced vehicle models as a first phase. A test method was needed which would provide an indication of injury levels to the occupants in the crashed vehicle so that this could be related to the MUARC study of what was happening in real life crashes. In addition, the test method needed to be an established standard which could be developed into a new ADR for frontal impact protection, if the program showed this was appropriate.

For this reason, the first phase of the crash program tested seven Australian produced vehicle models using the procedures set out in US Federal Motor Vehicle Safety Standard 208. These tests used state-of-the-art Hybrid III instrumented test dummies restrained in the front seating positions. The US regulation assesses performance by using established injury parameters recorded by the dummies during the crash test.

Having established the baseline performance of these vehicles, the program set out to examine what improvements could be achieved. To do this, the second phase took some of the possible countermeasures identified in the MUARC study, grouped them into three combinations and an optimisation program carried out to enable their fitment into one of the vehicle models used in the first phase of testing. This was done using computer simulation and laboratory tests.

The third phase was to fit these components into actual vehicles for crash testing to get an indication of likely improvements in real life crashes.

In parallel with the crash test program, a study on the cost-effectiveness and feasibility of the various safety options was carried out.

In summary, the total program demonstrated that the injuries occurring in real life crashes could be mitigated by a range of emerging technology which would be brought about by a new Australian Design Rule for frontal impact protection which sets out performance criteria based on established injury parameters, measured by instrumented dummies.

10 Performance Versus Component Specification

Currently, the Australian Design Rules follow the approach used in Europe and Japan in specifying the design requirements of the individual components which make up the occupant protection system in a vehicle. These requirements cover such items as:

- seat belts and the strength of their anchorages
- seats and the strength of their anchorages
- energy absorption of steering wheel
- steering column intrusion in a barrier crash test
- energy absorption of instrument panel
- energy absorption of sunvisors
- breakaway loads on internal rear vision mirrors.

The MUARC study (FORS Report CR 95 "Passenger Cars and Occupant Injury") showed that despite current vehicles meeting the requirements of the ADRs, occupants were still being injured in crashes.

The FORS crash test program confirmed international experience regarding the need to optimise the performance of the various components that make up the total occupant restraint system, eg seat belt webbing clamp retractors, seat belt pretensioners, airbags and other emerging safety technology, if their full benefits are to be realised. The work by NSW Crashlab also supported this observation.

Without optimisation to suit individual vehicle models, these new safety items may not show any benefit — it is not sufficient to specify the installation of particular components of a safety system.

As the aim of the project is to reduce injury, the outcome of this work should set a performance requirement to enable injury potential to be measured.

In summary, the outcome of the various elements of this program support a move to a performance based requirement specifying established injury parameters rather than the traditional approach of specifying individual components. In this way, the vehicle manufacturer is clearly accountable for the performance of the vehicle safety system as a whole.

11 Conclusions

The conclusions which can be drawn from the FORS standards development program are:

- The vehicle models used in the crash tests were built to conform with the current Australian Design Rules for vehicle safety which are comparable to standards in Europe and Japan. There were no unexpected structural failures observed during the crash tests.
- There are significant improvements possible with the range of emerging technology when properly engineered into a vehicle. These include seat belt webbing clamp retractors, seat belt buckle pretensioners, airbags and energy absorbing steering wheels.
- The FORS crash test program also showed that the implementation of a new Australian Design Rule for frontal impact protection which sets performance requirements based on the established injury parameters in US Federal Motor Vehicle Safety Standard 208 would lead to manufacturers introducing this new technology to achieve improvements in occupant protection.
- The FORS crash test program demonstrated that considerable development work would be required on current models on the Australian market to achieve performance levels high enough to give manufacturers confidence that all production vehicles would meet the requirements of a regulatory regime based on the American standard.
- The laboratory tests at NSW Crashlab highlighted the significant interaction between the different components of the total vehicle restraint system. When variations in physical stature and preferred driving position are also considered, the complexity in effectively optimising a restraint system becomes apparent. The benefits of these new safety items will not be realised unless their performance is carefully optimised for individual vehicle models.
- The feasibility study of occupant restraint countermeasures (13) showed that the combinations of improved restraint systems tested in the FORS crash test program (10) were cost beneficial and could be installed into vehicles within the next two to three years.
- The 'willingness to pay' feasibility study (14) provided a methodology to conduct a survey of the community's willingness to pay for safety improvements. The results of this survey will be available for consideration in the second half of 1992.
- There is further work to be carried out on the issues of offset frontal impact, side impact and, to a lesser extent rollover. This is expected to lead to regulatory requirements in the coming years.

In summary, the program confirmed that an Australian Design Rule based on FMVSS 208 injury criteria would bring about the fitment of a range of cost effective emerging safety technology including airbags and would lead to significant improvements in occupant protection.

12 Recommendations

In making recommendations as a result of this review, it should be remembered that any strategy to achieve improvements in occupant protection must be developed in the context that there are uniform compulsory seat belt regulations in Australia, with a wearing rate of over 90% in front seats.

Benefits will also flow from this strategy to the small proportion of motorists who do not wear seat belts where manufacturers fit airbags as part of their package to meet the frontal impact standards set out below.

12.1 Full Frontal Impact Protection

It is recommended that a new Australian Design Rule for full frontal impact protection be released for public comment which sets performance requirements based on the established injury parameters in US Federal Motor Vehicle Safety Standard 208. The proposed introduction date for the new ADR to be 1 July 1995.

The implications of this new Design Rule on other ADRs will be canvassed during the public comment period.

12.2 Offset Frontal Impact Protection

It is recommended that support be given to Australia's participation in the European Experimental Vehicle Committee's work to develop requirements for a global offset frontal test procedure.

12.3 Side Impact Protection

It is recommended that further work be carried out in Australia and developments be monitored overseas in the area of side impact with a view to adopting one or both of the dynamic side impact regulations developed by the US and European authorities.

12.4 Rollover Protection

It is recommended that action be taken by the Federal Office of Road Safety in conjunction with the Federal Chamber of Automotive Industries to introduce a code of practice on compliance with the static roof crush requirements in US FMVSS 216.

It is recommended that Australia monitor developments in the USA for a new dynamic rollover test.

12.5 Improved Restraint Systems

It is recommended that the use of lap only seat belts be examined with a view to considering requirements for the installation of lap sash seat belts in all seating positions of passenger cars.

It is further recommended that work continue to encourage, as much as possible, the integration of child restraint systems into the design of the vehicle.

BIBLIOGRAPHY

(1) Federal Department of Transport and Communications, "Australian Design Rules for Motor Vehicles and Trailers — Third Edition".

(2) Federal Department of Transport and Communications, "Single Uniform Type Inspection Manual for 3rd Edition Australian Design Rules".

(3) Federal Department of Transport and Communications, "Test Facility Inspection Procedures Manual".

(4) Federal Department of Transport and Communications, "Conformity of Production Manual".

(5) United States Department of Transportation, National Highway Traffic Safety Administration, "Federal Motor Vehicle Safety Standard No. 208 — Occupant Crash Protection", Federal Docket No. 571.208.

(6) United States Department of Transportation, National Highway Traffic Safety Administration, "Federal Motor Vehicle Safety Standard No. 214 — Side Door Strength — Passenger Cars", Federal Docket No. 571.214.

(7) United States Department of Transportation, National Highway Traffic Safety Administration, "Federal Motor Vehicle Safety Standard No. 216 — Roof Crush Resistance — Passenger Cars", Federal Docket No. 571.216.

(8) Federal Office of Road Safety Report CR 95 — "Passenger Cars and Occupant Injury" (Fildes, Lane, Lenard and Vulcan 1991).

(9) Gibson, T., Dal Nevo, R., Marx, W., "Occupant Restraint Project — Report on Stage 1". Roads and Traffic Authority of NSW, Crashlab, Special Report 90/183

Dal Nevo, R., Griffiths, M., Dowdell, B., "Occupant Restraint Technology Evaluation — Report on Stage 2". Roads and Traffic Authority of NSW, Crashlab, Research Note 4/91.

Dal Nevo, R., Griffiths, M., "Occupant Restraint Technology Evaluation — Report on Stage 3". Roads and Traffic Authority of NSW, Crashlab, Research Note 3/92.

(10) Seyer, K., "Occupant Protection — Crash Test Program". Federal Office of Road Safety, Report OR 11, 1992

(11) Clemo, K.C., Penoyre, S., White, M.J., "Safer Steering Wheels to Reduce Face Bone Fractures", Twelfth International Technical Conference on Experimental Safety Vehicles.

(12) Mertz, H. J., "Injury Assessment Values Used to Evaluate Hybrid III Response Measurements". Safety and Crashworthiness Systems, Current Product Engineering, General Motors Corporation, February 1984.

(13) Vulcan, P., Fildes, B., Cameron, M., Parish, M., Taylor, D., Stacy, M., Digges, K., "Feasibility of Occupant Protection Measures". Prepared by Monash University Accident Research Unit for Federal Office of Road Safety, Report CR 100, 1992.

(14) Federal Office of Road Safety Report CR 102, "Willingness to Pay for Vehicle Safety Features — Research Project", Dwyer Leslie Pty Limited, May 1992.