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Review of Passenger Car Occupant Protection — Crash Test Report

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Abstract

As part of a $1 million standards development program, the Federal Office of Road Safety crash tested ten cars at General Motors-Holden's facility in Victoria. All aspects of this program are reported in FORS Report OR 12 — "Review of Passenger Car Occupant Protection — Main Report". Seven cars were standard Australian mass-produced vehicles. The remaining three were vehicles fitted with improved restraint systems which included emerging technology such as airbags, webbing clamp retractors, buckle pretensioners and energy absorbing steering wheels. The tests used the procedures set out in US Federal Motor Vehicle Safety Standard 208 which specifies injury parameters for the head, chest and legs recorded by instrumented dummies. The tests provided a general indication of the safety performance of the Australian fleet and the likely improvements to be gained from developing a new Australian Design Rule based on FMVSS 208 which is expected to bring about the installation of emerging safety technology such as airbags.

Keywords

OCCUPANT PROTECTION, CRASH TEST, ADR, ROAD SAFETY, AIRBAG

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.
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    (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.

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Executive Summary

Introduction

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. Australia has led the world in requiring frontal impact protection for forward control passenger vans and the compulsory wearing of seat belts.

The current Australian Design Rules are closely aligned with international standards used in Europe and Japan. The ADR for frontal impact protection is similar to the regulations in those countries.

Despite the reductions in fatalities in the past two decades, the Federal Government has taken the further initiative of allocating $10 million for road safety research and public education over a three year period.

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

The study was carried out by the Monash University Accident Research Centre (MUARC) and showed that despite the improvements in vehicle safety, occupants were still being injured by contact with parts of the passenger compartment.

Following on from this study, the Federal Office of Road Safety embarked on a $1 million standards development program to improve protection for passenger car occupants. FORS Report OR 12 "Review of Passenger Car Occupant Protection — Main Report" covers all aspects of the standards development program.

This report covers the FORS crash test program which was part of the standards development program. The crash test series incorporated the following elements:

- Crash testing of seven Australian produced vehicles to provide baseline data (Phase 1)
- 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 (Phase 2)
- Three further crash tests on cars fitted with these enhanced safety systems (Phase 3)

Crash Test 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 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 study, group them into the following three combinations, and optimise their fitment into one of the vehicle models used in the first phase of testing:

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

This optimisation program was done using computer simulation and laboratory sled tests.

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

Test Procedure

The tests were conducted using state-of-the-art 'Hybrid III' dummies in the front seats and restrained by the vehicle's lap/sash seat belts. Impact speed was nominally 48 km/h and the procedures set out in FMVSS 208 were followed.

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

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

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 manufacturers, First Technology Safety Systems. Dummy calibrations were then performed before and after the test program and after each test by the NSW Roads and Traffic Authority's Crashlab.

Phase 1 Test Results

The vehicle models used in the Phase 1 crash tests were built to conform with the current Australian Design Rules for vehicle safety which are commensurate with requirements in Europe and Japan. There were no unexpected structural failures observed during the crash tests.

The tests indicated a difference in performance between the vehicles, mainly in the area of Head Injury Criteria (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 where test results over a number of tests of the same vehicle model have been found to vary by 20% or more.

The HIC value was generally 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 dashboard on the passenger side of one vehicle which produced a higher HIC than that recorded for the driver's position.

Passenger head contact with the 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.

Within the bounds of test variability, none of the vehicles tested was likely to cause significant injuries to the front seat occupants. The only exception was that the driver dummy response in one test indicated a significant injury was likely to the left leg.

The Ford Laser was chosen for development of the enhanced restraint systems to be crash tested in Phase 3 for the following reasons:

- it was the highest selling small car
- the smaller packaging providing designers more challenges in addressing occupant impact with the interior.
- it has adjustable upper seat belt mounting points which gave some scope for changing the belt geometry.
- it has a seat belt buckle mounted on the seat which facilitates mounting of a buckle pretensioner
- the belt loads were such as to provide scope for using buckle pretensioners and webbing clamp retractors which tend to make the restraint system stiffer thus increasing the belt loads.

Phase 2 Development Work

Development work was carried out by Autoliv Germany under contract to FORS to analyse the baseline data for the Ford Laser together with determination 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.

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. After the sled series, the airbag and buckle pretensioner firing times were finalised.

After completion of the sled series, prototype components were shipped to Australia for fitment into the three vehicles which were to be crash tested in Phase 3.

Phase 3 Test Results

Three further vehicles were crash tested at General Motors — Holden's test facility under contract to FORS.

The Phase 3 crash tests demonstrated one aspect of test variability in that, although the vehicles were built consecutively, they all exhibited different crash pulses.

The results showed that both the airbag and energy absorbing steering wheel were similarly effective in reducing the driver HIC.

The test also showed that buckle pretensioner and webbing clamp retractor were effective in reducing forward excursion of the occupants. This had the effect of reducing the HIC, chest deceleration and chest deflection especially on the passenger side where dashboard contact was avoided.

The buckle pretensioner was effective in reducing femur loads in that toepan intrusion was now the major cause of leg loading. In the baseline test with the standard restraint system, instrument panel intrusion was responsible for the maximum femur loads which were higher than the loads caused by the toepan intrusion.

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 sustainable comparison of the safety performance of each vehicle. This variability can be in the order of 20% or more. However, the test results provided the baseline data for the development of improved standards.

Because of differences in restraint systems and positioning of hardware in left hand drive vehicles, a model complying with the US regulations may not necessarily do so when tested in a right hand drive configuration.

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.

Therefore, it is important to stress that any regulatory standard to improve frontal impact protection should aim at injury mitigation and a means to measure it, rather than the specification of particular safety components.

Outcome of FORS Crash Test Program

The vehicle models used in the Phase 1 crash tests were built to conform with the current Australian Design Rules for vehicle safety which are commensurate with requirements 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 confirmed that there were significant improvements possible with the range of emerging technology when properly engineered into a vehicle.

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.

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 outcome of this crash test program supports 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.

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Phase 1 — Barrier Crash Tests

Background

The Australian Design Rules (ADRs) (1) set down a comprehensive range of performance and design requirements for motor vehicle safety and are among the most stringent in the world.

For example, Australia is the only country in the world, other than the USA and Canada, which has requirements in force for side impact crash protection. Australia also led the world in developing requirements for frontal crash protection of forward control passenger vehicles which have become increasingly popular here.

The ADRs cover a wide variety of safety requirements such as vehicle *impact testing, side door strength, steering system intrusion, seat belts,* child restraints, seat strength, brakes, tyres and other features to improve occupant protection.

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.

Despite these achievements, the Federal Government has taken the further initiative of allocating $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) embarked on a $1 million standards development program to look at ways to improve protection for passenger car occupants.

In 1989, the Federal Office of Road Safety commissioned a major study by the Monash University Accident Research Centre to determine how the Design Rules were performing on current vehicles on the road and recommend what improvements can be made.

This study, FORS Report CR 95 "Passenger Cars and Occupant Injuries" (2), released in April 1991, provided valuable information on the types and severity of injuries that people were sustaining and the parts of the vehicle which caused them.

The aim of the FORS crash test program was to provide test data to examine why this was occurring and the means to improve occupant protection. This program incorporated a series of crash tests with the following elements which is the subject of this report:

- Crash testing of seven Australian produced vehicles to provide base*line data (Phase 1)*

- 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 (Phase 2)
- Three further crash tests on cars fitted with these enhanced safety systems (Phase 3)

Current crash testing required by the Australian Design Rules, and other countries except the USA, assesses rearward displacement of the steering column. This series of tests assesses the likelihood of injury to occupants using instrumented dummies.

FORS Report OR 12 "Review of Passenger Car Occupant Protection — Main Report (3) draws together the following companion studies which are elements of the FORS standards development program:

- Monash University Accident Research Centre study on the cost effectiveness and feasibility of safety options
- A study of the feasibility and methodology to conduct a survey on 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

1 Test Procedure

1.1 Introduction

The test procedure used was that specified in the United States Federal Motor Vehicle Safety Standard 208 (FMVSS 208), with 'Hybrid III' dummies restrained in outboard front seating positions in a full frontal crash test at a nominal speed of 48 km/h. A copy relevant extracts of FMVSS 208 used for these crash tests is at Appendix 1.

Instrumentation and other detailed information not included in FMVSS 208 was obtained from Document TP-208-08, Laboratory Test Procedures for FMVSS 208 "Occupant Crash Protection" (4) published by the US Department of Transportation as test procedures to be used by their contractors for audit testing to FMVSS 208.

1.2 Test Requirements

1.2.1 Injury Parameters

The injury parameters set out in FMVSS 208 were used, viz:

(a) Head Injury Criterion (HIC) measured by accelerometers in the dummy's head (limit 1000). The value is the maximum cumulative integration of resultant head acceleration (a) over a time period (t_1 to t_2) not exceeding 36 milliseconds using the formula below.

$$\left[\frac{1}{(t_2-t_1)}\int_{t_1}^{t_2} a\,dt\right]^{2.5}(t_2-t_1)$$

(b) Chest Deceleration measured by accelerometers in the dummy's chest (limit 60 g except for values whose cumulative duration is not more than 3 millisecond).

(c) Compression Deflection of the Sternum relative to the spine (limit 76.2 mm).

(d) The force transmitted axially through the upper leg, femur load (10 kN).

In addition to the injury criteria, there was a requirement that all portions of the test Dummies remain within the vehicle passenger compartment during the crash test.

1.2.2 Impact Speed

The requirements of FMVSS 208 are that the test vehicle impact speed be 47.3 ± 0.8 km/h (4) (range of 46.5 to 48.1).

1.3 Test Vehicles

The test program involved seven Australian manufactured passenger vehicles. Each was fitted with automatic transmission and air conditioning. All vehicles with the exception of the Ford Laser was fitted with power steering. An eighth vehicle, the Nissan Pulsar, was dropped from the program as a model change was imminent.

The vehicles tested are listed below along with the laden test mass and indication of their drive configuration.

Vehicle Name	Laden Mass	Drive
Ford EA Falcon GL Sedan	1549 kg	RWD
Ford Laser GL Hatchback	1115 kg	FWD
Holden VN Commodore Executive Sedan	1446 kg	RWD
Mitsubishi Magna TR Executive Sedan	1446 kg	FWD
Nissan Pintara Executive Sedan	1289.5 kg	FWD
Toyota Camry Executive Sedan	1325 kg	FWD
Toyota Corolla GL Hatchback	1124 kg	FWD

The vehicles were selected at random from fleet vehicles delivered to the Federal Government's Department of Administrative Services so as to assure that the vehicles were representative of series production. Further, each vehicle was uniquely marked, their Vehicle Identification Numbers were recorded, and they were held in a secure area prior to test. The specifications of each vehicle are at Appendix 2.

Vehicles were marked with a Barrier Test (BT) number. BT numbers used were: 225, 228, 234, 235, 236, 237, 238. This test numbering will be used throughout this report to facilitate reference to different tests.

1.4 Vehicle Preparation

The vehicles were delivered to the test facility by car transporter after a pre-delivery inspection was carried out at the Department of Administrative Services garage.

To install the necessary test instrumentation, the modifications listed below were carried out. These changes were not considered to critically affect the crash performance of the vehicles.

- Rear bumper, plastic facias and tail-lamps were removed.
- A fifth wheel was attached to monitor vehicle speed.
- An abort device which applies the vehicle's service brakes was fitted.

- *Cut-outs were made in the front doors to allow positioning of high* speed cameras for recording the Dummies' lower torso trajectory. The side intrusion beams were not modified.

Where necessary, ballast was added to achieve the correct test mass.

To assist analysis of the crash event, the following additional preparation was carried out on all test vehicles:

- Underpan components were painted in distinguishing colours for ease of recognition. The vehicle exterior body was painted in matt white to facilitate photography.
- Interior features and possible contact areas were coated with a water/chalk compound to indicate Dummy contact.
- Targets were positioned on the vehicle body and target tape was fixed to underpan locations about the rear fuel tank, spare wheel well, floorpan bracing channels, engine and transmission pans and rocker panels.

The vehicles were prepared inside the test facility's vehicle emissions laboratory which is controlled for temperature and humidity.

1.4.1 Pre-Test Records

A photographic record was made of the vehicle and Dummy positioning. This sequence of photographs documented the position of the torso and the location of the limbs, particularly the legs and feet in relation to under dash components.

To enable a repeat test, if required, measurements were taken of the vehicle and Dummy positioning relative to datum points in the vehicle. These are provided in Appendix 3.

1.4.2 Post-Test Records

Photographs, similar to the pre-test sequence, were taken after the test and additional photographs were taken of areas indicating Dummy contact including steering wheel distortion, and glove compartment and under dash damage where appropriate.

Dummy contact is indicated in the photographs by the presence of chalk marks on the skin and clothing. The colour of the marking corresponds to the colour of the component contacted.

Photographs at Appendix 4 show the pre and post test condition of the vehicle and Dummies.

1.5 High Speed Photography

Both on and off board high speed cameras were used to gather base data on dummy trajectory for Phase 2 of the crash program.

1.5.1 High Speed Camera Orientation in Door Cavities

Ideally the camera should be aligned horizontally with the target point set to be in the middle of the expected range of travel of the knee pivot for accurate recording of Dummy kinematics.

Due to limitations caused by the location of the side door intrusion members, the cameras were positioned at an angle in some cases.

When the high speed film analysis was carried out for Phase 2, the data was adjusted to compensate for the camera angle.

The orientation of the cameras is set out below:

Vehicle	Camera-Angle(degrees)		Lens-to-Knee(mm)	
	Driver	Passenger	Driver	Passenger
BT225	0	0		
BT228	0	0	340	340
BT234	13	13	330	350
BT235	15	15	340	340
BT236	-12	-12	350	350
BT237	-20	-20	340	315
BT238	-19	-19	375	335

1.5.2 Off-Board High Speed Cameras

Six other cameras were positioned around the barrier to record the impact.

These cameras were Photosonic 16mm — 1B high speed cameras. They operate at frame rates between 850 and 900 frames per second giving about 5 seconds of operation with the 100 foot spools of film used.

A "time zero" flash on the vehicle and timing marks recorded on the film were to assist subsequent analysis.

2 Test Equipment

2.1 Barrier Test Facility

The seven barrier crash tests were conducted at the facilities of General Motors-Holden's Automotive Limited located at the Lang Lang Proving Ground, Victoria.

The laboratory is accredited by the National Association of Testing Authorities (NATA Approval No. 1842).

2.1.1 Barrier

The Lang Lang barrier facility is designed to comply with the requirements of Society Automotive Engineers' standard J850. The run up track is 130metres long and the barrier itself is a concrete block weighing some 60 tonnes. The impact face has an area measuring 3 by 3 metres. The test site is located outdoors with the impact area under cover.

2.1.2 Data Acquisition

The acquisition of barrier data is performed using Tektronix TestLab Model 2520 equipment. This equipment has the capability of capturing 64 kilosamples of data per channel, at a rate of up to 100 kilosamples per second. Resolution is 12 bits. Channel capacity is currently 64, but the equipment is expandable to 96 channels.

2.1.3 Tow Speed Control

Vehicle speed is determined by a fifth wheel attached to the rear of the car and by an amphometer positioned just prior to the impact.

The tow mechanism consists of a continuous loop wire rope, driven by a V8 car engine through an automatic transmission, differential and a series of drive pulleys. An experienced operator controls the tow speed manually via the engine throttle.

Tow connection was via two pieces of seat belt webbing attached to a dolly running along a single centre rail.

2.2 Test Dummies

'Hybrid III' dummies where used in both the driver's and front passenger's seating positions. 'Hybrid III' is an anthropomorphic test dummy which conforms to the requirements of US Federal Motor Vehicle Regulation No. 572, Test Dummies Specifications — Anthropomorphic Test Dummy for Applicable Test Procedures, Subpart E — Hybrid III Test Dummy — 50th

Percentile Male, published by the Unites States National Highway Traffic Safety Administration.

The Dummies used were Serial No.385 (Driver) and No.386 Passenger).

The Dummies were calibrated prior to the commencement of the test program by both the dummy manufacturer, First Technology Safety Systems, and New South Wales Roads and Traffic Authority's Crashlab.

Crashlab performed a full calibration of each dummy after each test. Where a calibration showed damage had occurred the affected parts were replaced and another calibration performed.

The Dummies used were fitted with the following transducers:

- Three Axis accelerometer in the head to measure deceleration;
- Three Axis accelerometer in the upper thorax to measure deceleration;
- Rotary Potentiometer for measuring chest deflection;
- Load Cell in each femur to measure the axial compressive loading of the femur;
- Three Axis accelerometer in the pelvis to measure deceleration.

The Dummies were positioned in the vehicle as specified by the test procedures in FMVSS 208, clothed as required, with limb joints set at the minimum loading required to keep them in place (nominally 1g). Further care was taken to ensure:

- That the umbilical cables would not prevent the Dummy from moving freely during the test;
- That the shoulder belt lay as straight as possible. This involved lightly taping the webbing in place due to the mass of the belt load cells;
- Correct positioning of the driver's legs.

2.3 Location of Additional Transducers and Load Cells

This set of instrumentation was installed to gather additional data for the second phase of the project to develop three enhanced restraint systems for fitment into vehicles for the Phase 3 barrier crash tests.

2.3.1 Seat Belt Assembly

Four load cells per assembly were placed on the seat belt webbing to measure loadings. These were positioned at the inner lap and lower sash area near the buckle, at the upper sash area between the upper sash guide and the dummy shoulder point, and the outer lap area near the anchorage point on the rocker panel.

Care was taken to position the transducers so they did not affect dummy kinematics, especially in the area of the lower ribs and iliac crest.

2.3.2 Floorpan

One three axis accelerometer was placed centrally on the floorpan in the area of the rear seat cushion to measure the deceleration pulse.

2.3.3 Seat Belt Buckle Mounting Point

One accelerometer per side (left & right) was installed for determining the triggering point for buckle pretensioners in the second phase of crash tests.

2.3.4 Rocker Panel

One accelerometer per side (left & right) was installed just behind the B-pillar.

3 Phase 1 Test Results

This section provides the results of the test series together with an indication of the dummy contact points with the vehicle interior which may have caused the dummy responses recorded.

3.1 Test Vehicle Speed

The requirements of FMVSS 208 are that the vehicle impact speed be 47.3 + 0.8 km/h (range of 46.5 to 48.1). The speeds at impact were generally towards the upper limit as detailed below:

Vehicle	Speed km/h
BT225	50.2
BT236	47.7
BT228	48.0
BT234	48.1
BT235	48.1
BT237	48.0
BT238	48.8

The crash pulses for each test vehicle are given in Appendix 5.

It should be noted that the impact speeds for BT 225 and BT 235 were above the target speed. This would be expected to give higher injury criteria results than tests conducted within the target speed range, especially in the case of BT 225.

3.2 Head Injury Criteria (HIC)

The HIC values ranged from 622 to 1012 for the Driver's side, and from 322 to 872 for the Passenger's side.

Generally the HIC value was lower for the Passenger than for the Driver. Head contact with the steering assembly, and also the instrument panel in the event of severe steering wheel deformation, is the likely reason for this. In BT225 there was heavy head strike on the dashboard on the passenger side which resulted in a higher HIC than the driver.

Passenger head contact with dashboard occurred in all vehicles except BT228, BT234 and BT238. In BT225, Passenger head contact also occurred with the glove compartment lid during the crash sequence.

3.3 Chest Deceleration

The Drivers' chest decelerations were between 45g and 60g while the Passengers' figures were between 40g and 50g.

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.

3.4 Chest Deflection

The Drivers' chest deflections were generally between 40mm and 50mm while those for the Passenger were between 30mm and 40mm.

Generally the chest deflections of the Driver were greater than those of the Passenger. This is attributed to Driver contact with the steering wheel.

The one exception was BT236 in which the Passenger's was marginally higher.

3.5 Femur Loads

Generally the femur loads were below 5kN and also usually lower for the Passenger than the Driver.

However, there were two major exceptions:

- 15.4kN reading for the Driver's left leg of BT235 which appears to have struck an object in the under dash area.
- 9.47kN reading for the Driver's right leg of BT238 which struck the ignition switch (punching a hole in the Dummy's knee skin).

Passenger loadings were low despite contact with under dash panels and glove compartment.

3.6 Lost Data

During the conduct of the barrier testing two instrument failures occurred in accelerometers measuring head deceleration and as a result affected the HIC for those vehicles. These are discussed below:

BT228:

Loss of data occurred from the X-axis accelerometer in the Passenger Dummy head. As this is the primary axis for deceleration (parallel to the longitudinal axis of the vehicle) the HIC could not be computed.

An attempt to construct a deceleration plot from analysis of the high speed film of the dummy kinematics did not result in data consistent with a situation where there was no head contact.

Therefore, no HIC value is reported for the Passenger.

BT 238:

Failure of the Y-axis (lateral) accelerometer occurred in the Passenger Dummy head. The values recorded from by the Driver's dummy were substituted in order to compute a value for the HIC. This value is given in the report.

It is expected that this would result in a slightly higher value for HIC than that recorded in testing. There was no head contact of the passenger dummy.

3.7 Discussion of Results

The tests indicated a difference in performance between the vehicles, mainly 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.

3.7.1 Injury Threshold

Bearing this test to test variability in mind, work done by Mertz (5) may be used as a basis for discussion of the test results.

Mertz describes 'Injury Threshold Level' as a level of human mechanical response (of the head, chest, legs etc) below which a specified injury does not occur and above which the specified injury will occur for a given individual.

It should be borne in mind that this threshold level will vary for different individuals because of age, build, physical condition etc.

Mertz further describes 'Injury Assessment Value' as a human response level below which a specified "significant" injury is considered unlikely to occur for a given individual. An "Injury Assessment Value' is a lower bound of its 'Injury Threshold Level'.

"Significant" injuries include:

- Serious injuries (AIS = 3)
- Reversible brain concussion
- Bone fractures
- Major injuries
    - life threatening injuries (AIS > 3)
      : brain damage
      : thoracic and abdominal organ damage
    - permanent impairment injuries (AIS > 2)
      : spinal cord damage
      : knee joint damage

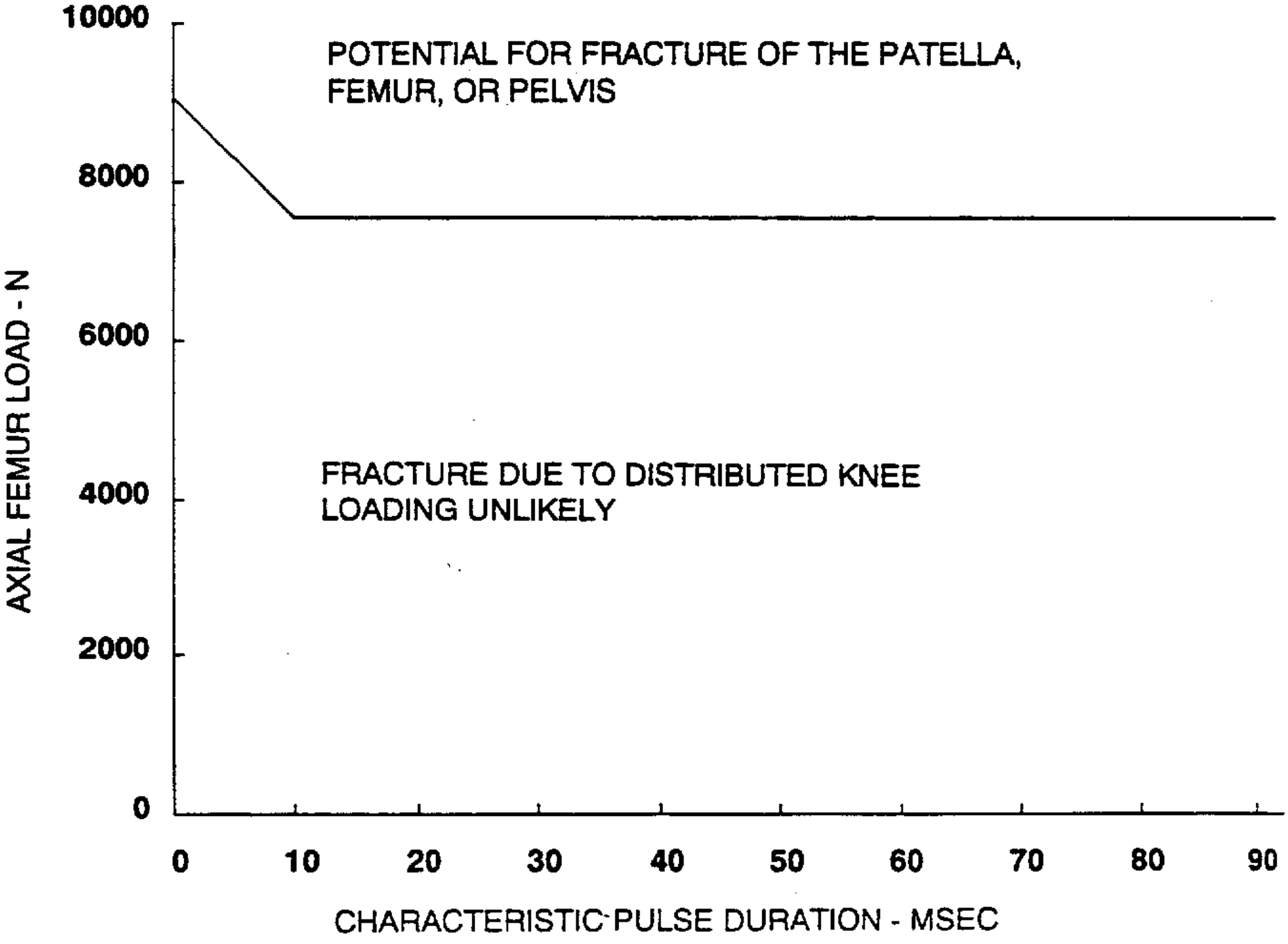
Note: AIS ratings based on the Abbreviated Injury Scale published by the American Association for Automotive Medicine.

Mertz suggests the following 'Injury Assessment Values' for the head and chest which are the limits for the injury parameters set out in FMVSS 208:

- HIC not greater than 1000
- Chest/spine acceleration not greater than 60g for more than 3 msec.
- Chest compression not greater than 50 mm for sash loading, and not greater than 75 mm for distributed frontal chest loading.

In addition, Mertz suggests a time dependent injury assessment criterion for distributed knee loading. This is shown in Figure A3.1.

Figure A3.1
Time dependent injury assessment criterion for distributed knee loading



Source: 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.

Using these 'Injury Assessment Values', the following comments can be offered on the vehicles tested:

A "significant" head injury to the driver and passenger is unlikely to occur in any vehicle. However, the HIC for the driver in BT237 is marginally over the threshold. The value for the driver is approaching the threshold for three vehicles, BT234, BT236 and BT238. The value for the passenger is approaching the threshold for two vehicles, BT225 and BT237.

A "significant" thoracic organ injury due to gross chest/spine acceleration is unlikely to occur to the driver and passenger in any vehicle. However, the value for the driver is near the threshold for two vehicles, BT225 and BT237.

A "significant" thoracic organ injury due to chest compression from the sash belt is unlikely to occur to the driver and passenger in an vehicle. However, the value for the driver is near the threshold for one vehicle, BT225.

A "significant" liver and/or spleen injury due to shoulder belt loading of the lower part of the lateral part of the rib cage is unlikely to occur to the driver and passenger in any vehicle.

Only for the driver's left knee in BT235 is there a potential for a "significant" leg injury to occur. However, the value for the driver's right knee in BT238 is very near the threshold for a "significant" injury.

Within the bounds of test variability, none of the vehicles tested produced dummy response which were likely to be life threatening for the front seat occupants.

3.7.2 Non-Contact HIC

There has been considerable debate overseas on HIC figures when using Hybrid III dummies where no head contact has occurred with vehicle's interior.

The issue centres around the flexible biofidelic neck fitted to Hybrid III dummies which Hybrid II dummies do not have.

Since HIC is calculated by integrating, over a period of time (36 msec), the resultant deceleration recorded from a transducer mounted in the dummy's head, a large value can be recorded due to the "whipping" action of the Hybrid III neck even though the head has not made hard contact.

To address this, some vehicle manufacturer's have petitioned the US National Highway Traffic Safety Administration (NHTSA) to use a 15 msec integration period to calculate HIC when Hybrid III dummies are used. This is based on research which indicates that the shorter integration period did not alter the HIC figure when hard contact was involved, but did give a more representative (lower) figure when no head contact occurred.

Table A3.3 provides the HIC values calculated using both 15 msec and 36 msec integration periods. The table notes the tests where no head contact occurred and gives an indication of the severity of the head strike.

3.7.3 Test Variability

There has been research done in the USA on the issue of test to test variability. The following are two examples of this work.

In the mid 1970s, thirty three Mercury airbag equipped cars of the same model type were tested in three different laboratories in side, oblique and full frontal crash tests (6). Of the fifteen vehicles used for full frontal tests, the driver HIC varied up to 22% of the mean value and the passenger HIC varied up to 28% of the mean value.

In 1983, a number of test facilities contracted to NHTSA conducted barrier crash tests at 35 mph (55 km/h) on sixteen Chevrolet Citations of the same specification. The driver HIC varied up to 20% of the mean value and the passenger HIC varied up to 10% of the mean value.

This work assumes that the test results follow a normal distribution. The percentage variation given above is for one standard deviation from the mean value which suggests that about 70% of all test results will fall within the quoted number of percentage points either side of the mean value.

In terms of HIC numbers, using the Mercury tests as an example, if the mean value was 500 then one standard deviation would be 110. Therefore, 70% of the test results would be expected to fall in the range 390 to 610.

It should be noted that variability will depend on several factors including whether the same dummies are used, calibration techniques, and vehicle model characteristics (restraint system effectiveness, crash pulse etc.).

In summary, this work indicates test to test variability can be in the order of 20% or more.

3.8 Summary of Results

Individual injury criteria by type are listed in Table A3.1. Bar charts comparing the barrier test vehicles for each injury criteria are contained in Appendix 6. The Dummies' pelvic decelerations and seat belt webbing loads are listed in Table A3.2.

It must be remembered that the comments regarding the results may change if further tests are conducted because:

- The comments only apply to results obtained from one test and no statistically valid comparison of safety performance can be made.
- The results for some vehicles are close to the threshold values.

Table A3.1
FORS Crash test Program – Phase 1
Injury Criteria Results

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
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 due to instrument failure. No head contact occurred.

Table A3.2
FORS Crash test Program — Phase 1
Seat Belt Loads and Pelvic Deceleration

Vehicle	BT225		BT228		BT234		BT235		BT236		BT237		BT238	
	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass
Sash Belt Loads (kN)														
Upper	6.0	6.6	13.7	7.5	6.6	7.3	6.8	6.5	6.1	6.9	7.0	6.8	6.9	6.8
Lower	5.5	5.7	9.5	8.7	8.4	6.9	6.9	8.8	11.8	10.6	10.5	11.0	8.9	10.1
Lap Belt Loads (kN)														
Inner	13.6	13.4	13.6	15.5	10.3	13.2	9.8	12.8	15.0	15.5	8.8	11.2	9.9	12.0
Outer	7.6	7.0	7.7	10.2	5.8	7.1	6.0	6.3	11.3	24.0	7.9	11.0	5.4	7.9
Pelvic Decel (g)	43.7	46.3	58.3	46.0	43.3	42.2	70.0	35.0	56.5	47.6	70.0	40.0	61.0	48.0

Table A3.3
FORS Crash Test Program — Phase 1
Contact (HIC 36) and Non-Contact (HIC 15) Figures

Test Vehicle	HIC (36 msec)		HIC (15 msec)		Comment
	Driv	Pass	Driv	Pass	
BT 225	622	872	594	832	
BT 228	779	N/A	547	N/A	No passenger head contact
BT 234	882	322	759	143	No passenger head contact
BT 235	623	523	433	282	
BT 236	848	699	848	645	
BT 237	1012	860	719	841	
BT 238	820	#445	716	#258	No passenger head contact

Notes:
N/A for BT228 does not contain the Passenger HIC, which was lost during the test.
for BT238 uses the Y-axis deceleration of the driver in calculating passenger HIC due to instrument failure.

4 Selection of "Phase 2" Test Vehicle Model

4.1 Selection Parameters

A vehicle model needed to be chosen for 'Phase 2' of the program to examine the likely improvements in occupant protection using a range of new safety technology. The choice was made using the following parameters:

Vehicle sales
Size of vehicle
Design features which may assist Phase 2 development work

It is important to remember that within the bounds of test variability, none of the vehicles tested produced dummy response which were likely to be life threatening for the front seat occupants.

The test results could not be used to rate the safety performance of the vehicles tested.

However, knowledge of the dummy kinematics and loadings experienced by the restraint systems assisted in selecting a vehicle model for Phase 2 which might reduce the problems encountered during the development of the enhanced restraint systems.

Vehicle sales were used because the more vehicles of a particular model on the road, the higher the exposure of occupants to a crash situation.

The size of the vehicle was used because a small vehicle presents more challenges to designers due to space limitations.

Design features such as adjustable upper torso anchor points allow some scope for changing the seat belt geometry and hence the dummy kinematics. Seat mounted seat belt buckles facilitate the installation of buckle pretensioners.

4.2 'Phase 2' Test Vehicle

The Ford Laser was chosen for development of the enhanced restraint systems to be crash tested in Phase 3 for the following reasons:

- it was the highest selling small car
- the smaller packaging providing designers more challenges in addressing occupant impact with the interior.
- it has adjustable upper seat belt mounting points which gave some scope for changing the belt geometry. This was the only model of the seven tested to have this feature.

- it has a seat mounted seat belt buckle which would facilitate the installation of a buckle pretensioner
- the belt loads were such as to provide scope for using buckle pretensioners and webbing clamp retractors which tend to make the restraint system stiffer thus increasing the belt loads.

5 Outcome of Phase 1 Crash Tests

The vehicle models used in the Phase 1 crash tests were built to conform with the current Australian Design Rules for vehicle safety which are commensurate with requirements in Europe and Japan. There were no unexpected structural failures observed during the crash tests.

The results demonstrated that there is room for improvement and 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.

It is important to note that due to test to test variability, the test results from this program do not form a basis for drawing statistically sustainable comparison of the safety performance of each vehicle. Test variability could be in the order of 20% or more.

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 dashboard 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. In one vehicle, passenger head contact with the glove compartment lid also occurred during the crash sequence.

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. There were two cases of high loadings caused by contact onto hard objects in the underdash area.

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. Only in the case of the driver's left knee in test BT 235 was significant injury likely to occur.

Part B

Phase 2
Development of Enhanced Restraint Systems

Phase 2 — Development of Enhanced Restraint Systems

1 Introduction

The second phase of the Federal Office of Road Safety crash test program involved Autoliv in Germany analysing the crash test data for the Ford Laser to develop the following three enhanced safety systems:

- Energy absorbing steering wheel developed by UK Transport and Road Research Laboratory (TRRL) (7), buckle pretensioners and webbing clamp retractors.
- Driver's facebag and standard restraint system.
- Driver's facebag, buckle pretensioners and webbing clamps.

This work was required to determine the optimum deployment time for the airbag and buckle pretensioner as well as tuning the characteristics of the restraint system to ensure injury reduction.

2 Computer Modelling

2.1 Set Up of Basic Computer Model

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 including:

- crash pulse (at buckle mounting points, rocker panels and floorpan near rear seat)
- instrument panel characteristics
- seat characteristics
- examination of dummy kinematics
- seat belt loads and general restraint performance
- toepan, instrument panel and steering assembly intrusions.

In addition to measurements made to determine the restraint system characteristics, the following stiffness measurements were made on components which were contacted by the dummies during the crash test:

- seat cushion towards the rear (initial sitting position of the dummy)
- seat cushion towards the front (in the effective contact area of the dummy during the crash sequence)
- steering wheel upper and lower rim areas
- steering wheel hub area
- rotational stiffness of the steering wheel versus the steering column
- steering column axial stiffness
- passenger side dashboard (crash pad)
- knee contact surfaces driver's side
- knee contact surfaces passenger's side

A computer model, MADYMO 2D developed by TNO (Research Institute for Road Vehicles) in the Netherlands, was used to analyse this information to examine correlation between the basic computer model and the actual BT 237 crash test. Information obtained from analysis of the high speed film of the crash was also used.

2.1.1 Correlation of Basic Computer Model to Crash Test

The comparison of results of the basic computer model and the crash test is given in Table B1.

There was good correlation of the time histories and maxima of dummy response between the simulation and the actual crash test.

The only exception was in the area of pelvic deceleration, which was thought to be the result of the inner seat adjuster unlatching on the passenger side during the crash test. This caused a reduction in belt loads when unlatching occurred (as evidenced by the belt load plots from the crash test) resulting in a change to the dummy kinematics.

This unlatching was modelled initially for correlation of the basic model with crash test. However, another simulation run was set up where the seat was fixed quite stiffly to the vehicle floor. Table B2 shows the comparison of the 'fixed' seat simulation with the basic model. The 'fixed' seat simulation was then used as the basis of comparing the effects of restraint system modifications in later computer runs.

2.2 Simulation of New Safety Technology

Once this basic correlation was established, simulation runs were conducted to analyse the effect on dummy kinematics of the individual devices under consideration for both driver and passenger.

The Autoliv KC1 webbing clamp retractor was simulated against the standard retractor.

A pre-tensioning distance of 42 mm was simulated for the buckle pretensioner. This means that the buckle is pulled down and back by 42 mm. Due to the very late increase in belt forces in the crash sequence for this vehicle, this was regarded as a realistic figure.

The firing time of the pretensioner sensor system was calculated from the crash pulse measured at the buckle mounting point in test BT 237. The firing time was set at 18 milliseconds after impact with pre-tensioning completed by about 28 milliseconds.

It was assumed that the pretensioner would be attached to the seat, therefore some flexibility for the anchorage point was introduced into the simulation model.

The Autoliv 'Eurobag' (30 litre facebag) was simulated with a trigger time of 30 milliseconds after impact. Vent sizes were optimised for each restraint system separately:

- 35 mm for the basic belt system
- 36 mm for the system with either webbing clamp retractor or buckle pretensioner
- 38 mm for system with both webbing clamp retractor or buckle pretensioner

Further modelling was then carried out to examine the three combinations of enhanced safety systems mentioned in the introduction.

The driver's side simulation runs are summarised in Table B3. Figures B1 and B2 are bar charts representing the changes relative to the basic model.

The passenger's side simulation runs are summarised in Table B4. Figures B3 and B4 are bar charts representing the changes relative to the basic model.

2.3 Discussion of Results of Computer Modelling

The results of the computer modelling (8) show that the cumulative effect of including combinations of the components into the restraint system is greater than any of the individual effects. This demonstrates the benefit gained through the interaction between the individual components.

There is further scope for improving the restraint system by:

- optimisation of the webbing and geometry of anchorages
- seat development
- steering wheel development (this was examined in the sled testing using the TRRL energy absorbing steering wheel)
- improvements in instrument panel design.

2.3.1 Changes to Driver Dummy Response

The head trajectory is modified by the closer coupling of the occupant to the crash pulse by incorporation of webbing clamp retractors and buckle pretensioners. This results in the head striking the steering wheel hub which is usually stiffer, which raises the HIC value although the velocity of impact is reduced. There is scope for injury mitigation with the use of an airbag or steering wheel with an energy absorbing hub. Chest deceleration is reduced.

The addition of the airbag reduces the upper torso injury criteria significantly.

The inclusion of the webbing clamp retractor and buckle pretensioner decreases the lower torso injury criteria significantly. The airbag has minimal effect on lower torso injury.

2.3.2 Changes to Passenger Dummy Response

Similarly, the head trajectory for the passenger is modified by the closer coupling to the crash pulse when webbing clamp retractors and buckle *pretensioners are incorporated. These items prevent head contact with* the crash pad, thereby reducing HIC values.

Lower torso deceleration and maximum femur loads are reduced by the closer coupling of the occupant by incorporation of webbing clamp retractors and buckle pretensioners. The maximum femur loads were now caused by toepan intrusion instead of loading due to knee contact with the dashboard/glovebox.

Table B1

FORS Crash Test Program — Phase 2
Comparison of Basic Computer Simulation and Crash Test Results

	Driver			Passenger		
	Simul.	Test	Diff. (%)	Simul.	Test	Diff. (%)
Head						
HIC 36	1039	1012	3	1065	860	24
t1 - t2 [ms]	74 - 104	75 - 106		74 - 109	86 - 106	
HIC 15	823	719	14	884	841	5
t1 - t2 [ms]	81 - 95	81 - 96		87 - 102	90 - 105	
3 ms [g]	75	76	-1	106	99	7
Chest						
3 ms [g]	54	59	-8	45	43	4
Deflection [mm]	43	43	0	37	29	27
Pelvis						
Max. acc. [g]	75	61	23	60	41	46
Femur Loads						
Force [kN] L + R	8,9	10,9	-18	4,1	4,1	0

Source: Autoliv, "Report on MADYMO Crash Victim Simulation of FORS Crash Test BT 237 forFull Frontal Impact at 48 km/h — Evaluation of Webbing Clamp Retractor, Buckle Pretensioner and Eurobag" for the Federal Office of Road Safety.

Table B2

FORS Crash Test Program — Phase 2
Comparison of Passenger Side Basic Simulation and 'Fixed' Seat Simulation

	Basic Simulation	'Fixed' Seat Simulation
HIC 36	1065	1128
Duration (t1-t2) (msec)	74–109	76–107
HIC 15	884	880
Duration (t1-t2) (msec)	87–102	88–102
Head Decel 3 msec clip (g)	106	90
Chest Decel 3 msec clip (g)	45	47
Chest Deflection (mm)	37	41
Pelvic Decel (g)	60	67
Femur Loads (L+R) (kN)	4.1	4.4

Source: Autoliv, "Report on MADYMO Crash Victim Simulation of FORS Crash Test BT 237 forFull Frontal Impact at 48 km/h — Evaluation of Webbing Clamp Retractor, Buckle Pretensioner and Eurobag" for the Federal Office of Road Safety.

Table B3

FORS Crash Test Program — Phase 2
Driver side computer simulation results

Equipment configurations

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

Simulation results

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

Source: Autoliv, "Report on MADYMO Crash Victim Simulation of FORS Crash Test BT 237 forFull Frontal Impact at 48 km/h — Evaluation of Webbing Clamp Retractor, Buckle Pretensioner and Eurobag" for the Federal Office of Road Safety.

Table B4

FORS Crash Test Program — Phase 2
Passenger side computer simulation results

Equipment configurations

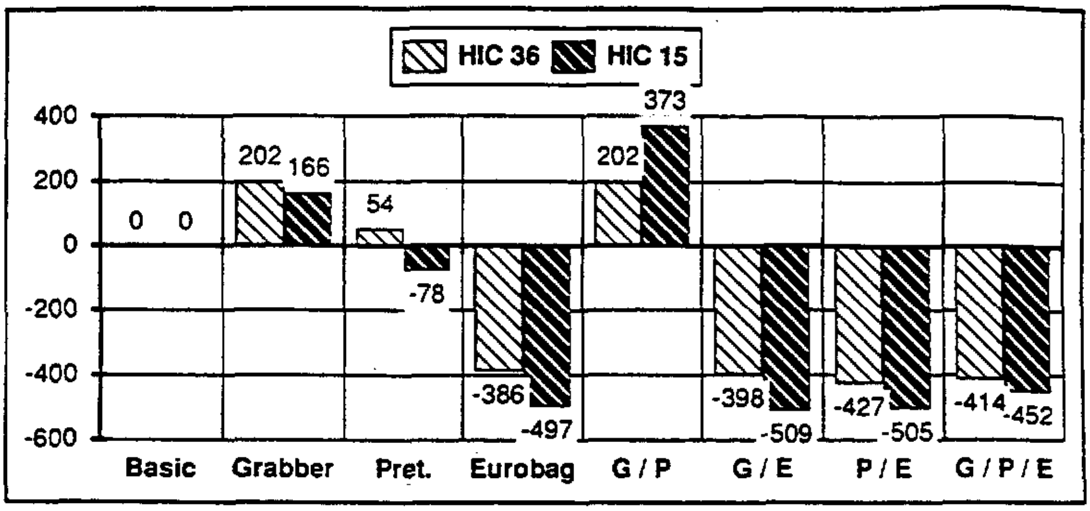
	Grabber	Pretensioner
Run		
1	-	-
2	+	-
3	-	+
4	+	+

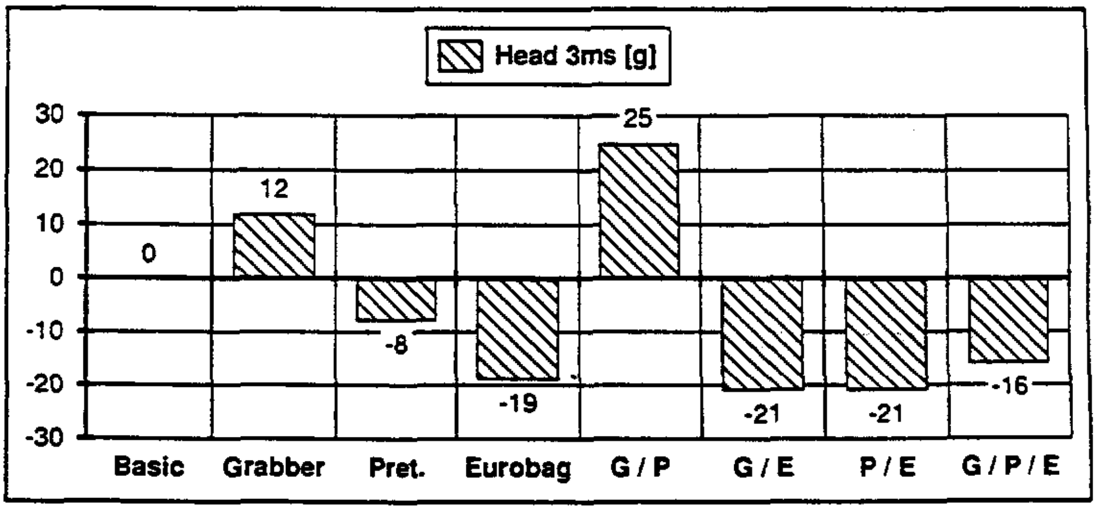
Simulation results

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

Source: Autoliv, "Report on MADYMO Crash Victim Simulation of FORS Crash Test BT 237 forFull Frontal Impact at 48 km/h — Evaluation of Webbing Clamp Retractor, Buckle Pretensioner and Eurobag" for the Federal Office of Road Safety.

Figure B1
FORS Crash Test Program — Phase 2
Changes relative to basic computer simulation model of HIC and head deceleration for driver

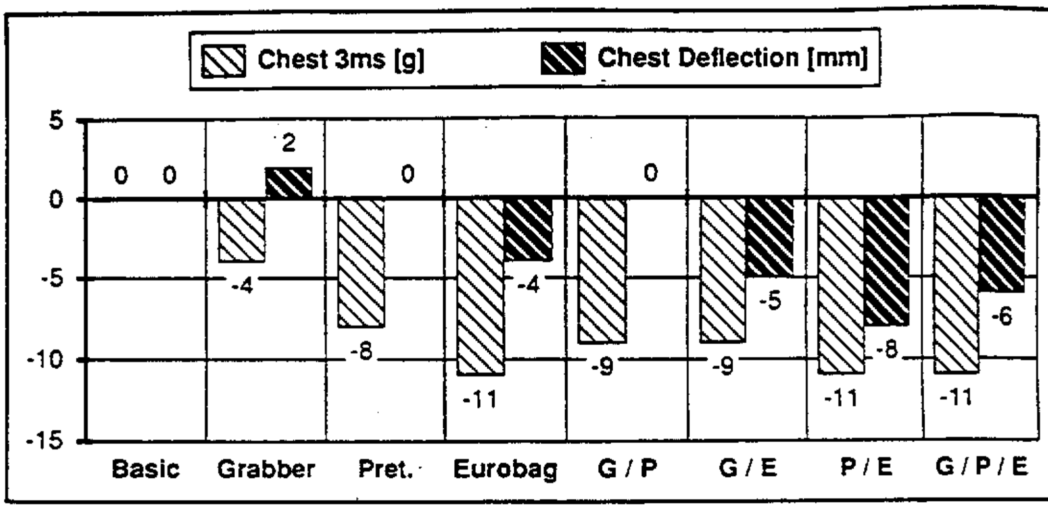


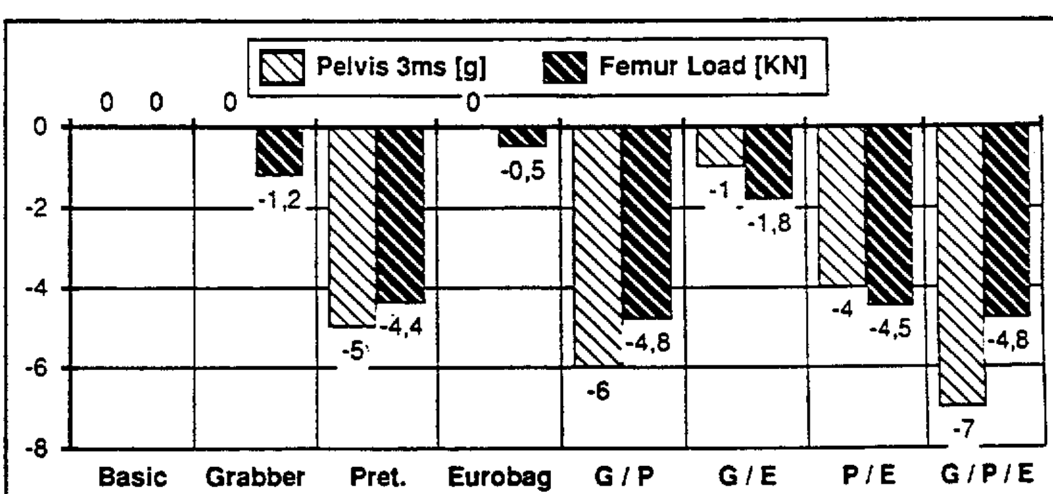


Source: Autoliv, "Report on Sled Tests on Ford Laser — Evaluation of Modified Belt System, Energy Absorbing Steering Wheel and Eurobag" for the Federal Office of Road Safety.

Figure B2

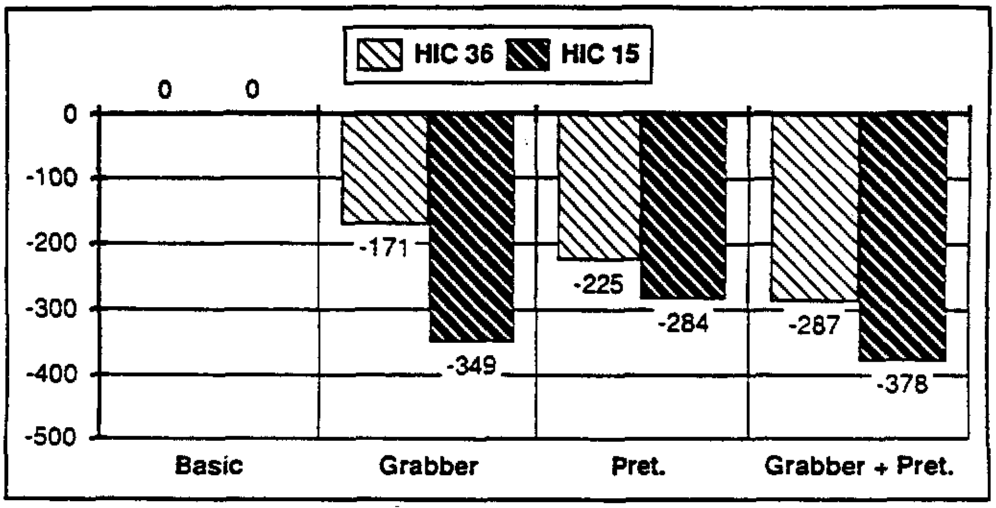
FORS Crash Test Program — Phase 2
Changes relative to basic computer simulation model of chest, pelvis and leg parameters for driver

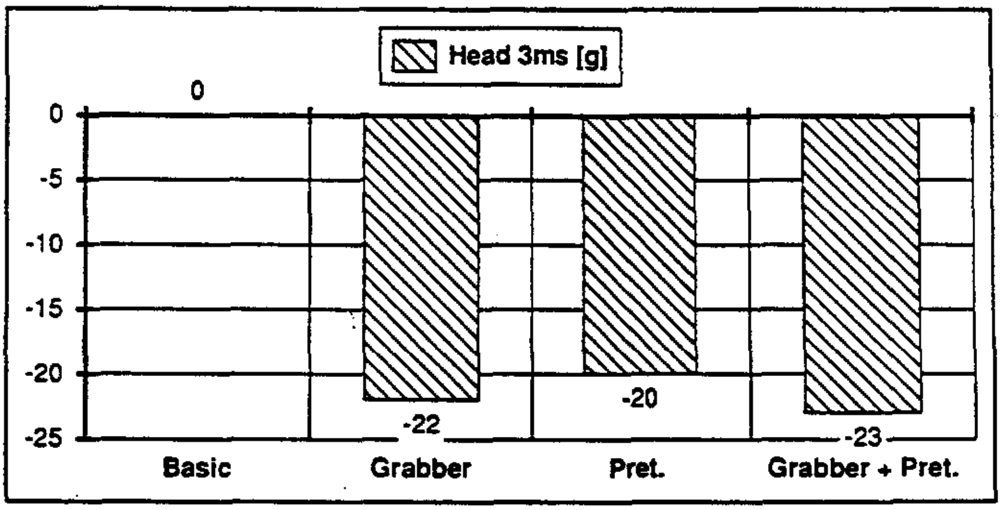




Source: Autoliv, "Report on Sled Tests on Ford Laser — Evaluation of Modified Belt System, Energy Absorbing Steering Wheel and Eurobag" for the Federal Office of Road Safety.

Figure B3
FORS Crash Test Program — Phase 2
Changes relative to basic computer simulation model of HIC and head deceleration for passenger

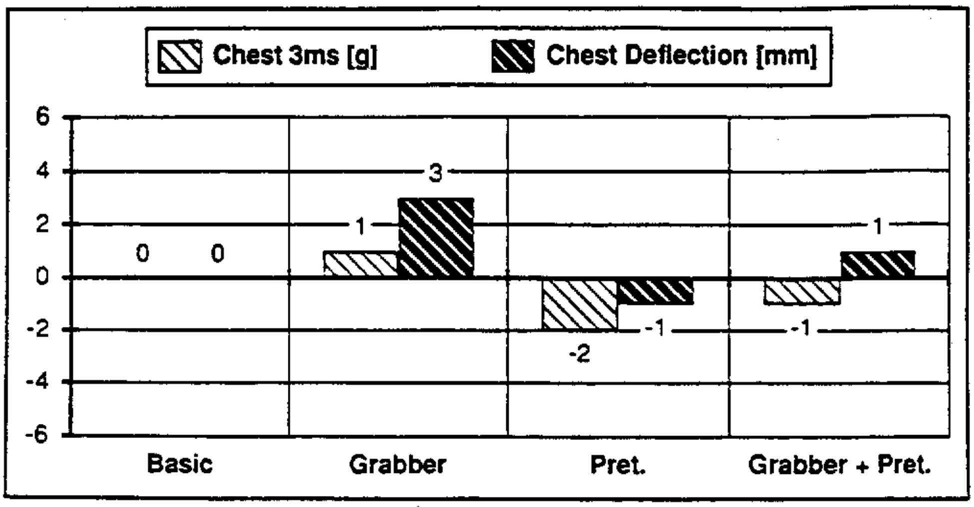


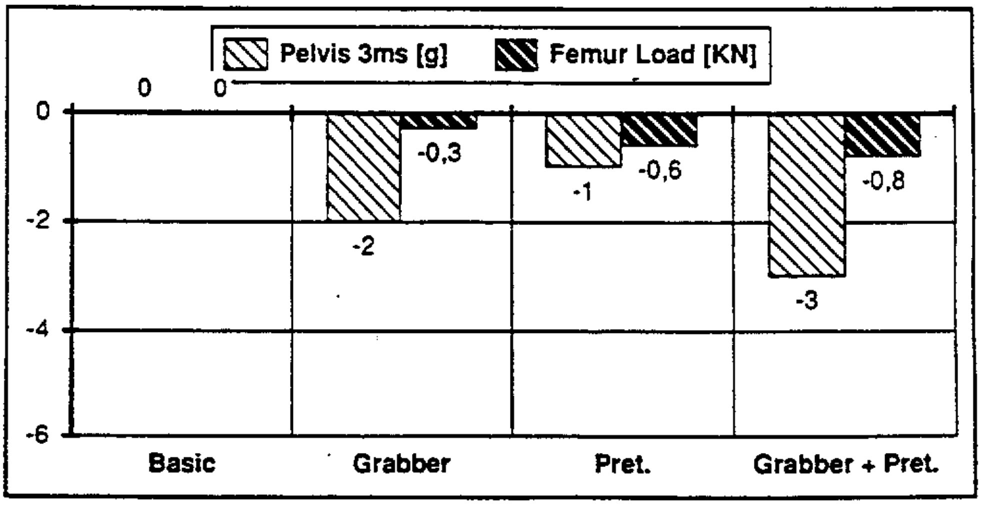


Source: Autoliv, "Report on Sled Tests on Ford Laser — Evaluation of Modified Belt System, Energy Absorbing Steering Wheel and Eurobag" for the Federal Office of Road Safety.

Figure B4

FORS Crash Test Program — Phase 2
Changes relative to basic computer simulation model of chest, pelvis and leg parameters for passenger





Source: Autoliv, "Report on Sled Tests on Ford Laser — Evaluation of Modified Belt System, Energy Absorbing Steering Wheel and Eurobag" for the Federal Office of Road Safety.

3 Sled Tests

Following completion of the computer simulation, the systems were fitted to a vehicle body shell for validation of the computer predictions on a sled for a full frontal impact at 48 km/h based on the crash pulse from the baseline test.

The sled series examined the effect of the following components on the level of occupant protection provided by the restraint system:

- TRRL energy absorbing steering wheel
- Autoliv KC1 seat belt webbing clamp retractor
- Autoliv seat belt buckle pretensioner (recoil spring type)
- Autoliv facebag (Eurobag) of about 30 litres volume.

The test matrix of these components in the sled series is given in Table B5.

3.1 Test Facility

The sled tests using Hybrid III dummies were conducted at Autoliv's indoor crash test facility in Dachau, Germany. The same facility can be used for whole vehicle barrier crash tests or sled tests.

The sled trolley is accelerated by a hydraulically driven endless rope. The deceleration pulse is determined by the impactor on the front of the sled penetrating into a series of cross bars of different section which can be changed to tune for different crash pulses.

The main specifications of the facility including data acquisition equipment are given below:

- Maximum speed of 80 km/h for mass of 2000 kg
- Maximum start acceleration of 0.4 g
- Track length of 55 m
- On board data acquisition system manufactured by Messring
  - 54 channels with amplifiers and semi conductor memory on trolley
  - sampling rate of 20 kHz/channel in general with 100 kHz/channel some data reduced to 20 kHz during format conversion.

The positioning of transducers, cameras and test dummies for the sled tests is given in Appendix 7.

3.2 Sled Test Set up

A complete vehicle was shipped to Germany and the running gear, doors and trim which were considered unlikely to affect front occupant kinematics were removed.

The remaining vehicle body was mounted onto the sled trolley and strengthened in critical load bearing areas to limit distortion from test to test so that set up variations were not introduced.

The best correlation between crash testing and sled testing is normally achieved when the dummy kinematics are similar in each type of test.

Sled testing does not reproduce the dynamic intrusion of the vehicle structure and components which is found in actual crashes. To best simulate this dynamic intrusion, the positions of the instrument panel, steering wheel/column and toepan area were modified to replicate the intruded condition based on the high speed film and measurement of the Phase 1 test vehicle. The steering column was mounted in the position at the time of contact with the dummy's head in the car crash.

The vehicle crash pulse and velocity change were simulated by a series of calibration sled shots to achieve a reasonable correlation to the crash conditions of the vehicle compartment. The method of 'Residual Deformation' (9) detailed below was used to determine a sled pulse which showed good correlation with the crash pulse:

- plot the displacement curve of the vehicle compartment (second integral of the deceleration curve)
- plot the displacement curve of a 'free flying mass' (FFM) for the vehicle impact velocity
- determine the point on the FFM curve corresponding to the maximum displacement of the compartment
- calculate the difference between that point on the FFM curve and compartment displacement. This figure represents the 'Residual Deformation' in millimetres
- perform the same calculation for the sled pulse. The sled pulse correlates with the vehicle pulse when the two 'Residual Deformation' values are equal.

3.3 Results of Passenger Side Sled Tests

The results of the sled series (10) are summarised in Table B6.

3.3.1 Test X00B0001

This test used the standard restraint system to establish a baseline. It showed good correlation to the crash test in that the timing of the events were similar. The inner seat adjuster unlatched at about 63 millisecond in a similar way to the vehicle crash.

3.3.2 Test X00B0002

This test was conducted to establish baseline criteria using a seat with the adjusters welded up. However, the pedestal attaching the seat adjuster to the floor broke at the foot of the mounting point to the vehicle floor at about 67 millisecond. The test was not repeated due to limited supply of components.

3.3.3 Test X00B0004

This test was conducted to examine the effect of the KC1 webbing clamp retractor with low elongation webbing (7%). The results were rendered invalid due to the failure of the adjustable shoulder anchorage (ASA) assembly at a load of 8 kN. The load at the ASA was 6.8 kN in the vehicle crash and 7.2 kN in the correlation sled test X00B0001. The ASA was eliminated from the remaining tests for both driver and passenger. High speed was not developed for analysis.

3.3.4 Test X00B0006

This was the repeat test of X00B0004 with the webbing clamp retractor fitted.

Head contact with the crash pad was eliminated through reduced dummy excursion. Maximum head motion in the x-direction was 450 mm compared with 610 mm in the baseline sled test. Maximum head deceleration was 68 g compared with 132 g in the baseline sled test. The HIC36 value is higher at 884 than the 690 recorded in the baseline sled test. However, the HIC15 value of 452 compared to 528 demonstrates more clearly the improvement by eliminating head contact.

The webbing clamp retractor with low elongation webbing induced higher seat belt loads and chest acceleration. This is due to the dummy's closer coupling to the vehicle pulse and the stiffer restraint system.

3.3.5 Test X00B0007

This test incorporated a restraint system using a buckle pretensioner and webbing clamp retractor.

The effect of the buckle pretensioner in removing slack from the system when compared with test X00B0006 is particularly evident in the reduction in chest and pelvic decelerations together with a reduction in belt loads. The closer coupling reduces the head forward movement by about 50 mm from that of test X00B0006. Although the head deceleration curve does not show any hard contact with the crash pad, there is a second lower peak on the curve indicating a possible soft head contact. There is also a flattening of the head contact curve which indicates a change in head attitude. The high speed film is not clear in this area but there is a possible contact between the dummy's forehead and thighs.

It is worth noting that the combination of toepan intrusion and soft seats causes the thighs to adopt a steep angle which would increase the potential for head/thigh contact. A stiffer seat cushion would certainly improve the dummy kinematics both for the above condition and also to improve the lap belt angle which can become very shallow. The pretensioner helps to keep this angle steeper in this test compared to test X00B0006. This steeper belt angle makes the occupant less susceptible to "submarining" (belt slipping over the iliac crest into the abdominal cavity).

3.4 Results of Driver's Side Sled Tests

The results of the sled series (10) are summarised in Table B6.

3.4.1 Test X00B0003

This was conducted as the correlation test to the crash test.

The head acceleration curve is shorter than the actual crash because of the absence of dynamic intrusion of the steering wheel. This shorter duration results in a lower HIC value of 558 compared to 1012 for the actual crash test. However, the maximum head deceleration (3 millisecond clip) is similar at 77 g compared to 80 g for the crash test. The sled test showed earlier contact between head and wheel at 76 millisecond while contact was at about 80 millisecond in the vehicle crash.

Chest injury criteria were higher in the sled test than the crash test probably due to the prolonged contact with the steering wheel. Peak chest deceleration was at 75 millisecond in the vehicle crash and at 72 millisecond in the sled test.

The femur load curves and pelvic deceleration curves do not reflect the effects of dynamic toepan intrusion in that the sled test curves do not have the initial peak of the vehicle crash. However, the femur loads are higher and occur earlier than the crash test, probably due to the set up of the dashboard in the maximum intruded position.

However, Autoliv considered that this test showed sufficient correlation for it to be used as a reasonable basis for evaluation of the various component combinations.

3.4.2 Test X00B0005

This test was designed to evaluate the effect of the KC1 webbing clamp retractor with low elongation webbing (7%) and the TRRL energy absorbing steering wheel.

Although the seat track was welded to prevent any potential for unlatching of the seat adjuster, the test results were rendered invalid by the fracture of the seat mounting point at the floor. Test X00B0011 is a repeat of this test with a reinforced mounting point.

The high speed film showed that the seat mounting fractured at about 63 millisecond at about the same time as the chest contacted the lower rim of the steering wheel. The head trajectory was modified by the seat movement and contacted the steering wheel rim at 73 millisecond (chin) and the top of the head at about 83 millisecond. The energy absorbing characteristics of the wheel reduced the potential sharp peak of the standard wheel with the HIC values only marginally higher than the baseline sled test where there was no seat movement.

3.4.3 Test X00B0008

This test was conducted to determine the effect of the combination of webbing clamp retractor with low elongation webbing (7%), buckle pretensioner and TRRL steering wheel.

The head trajectory is modified by the action of the seat belt system components and contact with the steering wheel is made at the top portion of the hub at 77 millisecond. The closer coupling of the dummy to the crash pulse caused the upper torso movement to be reduced thus directing the head to a lower level. Although the HIC values were high at 858, review of the deceleration curve shows that the peak head deceleration was lowered (from 210 g to 92 g) while the duration is extended which has the effect of making the HIC calculation higher.

The effect on the chest is that the peak deceleration is lowered considerably (from 68 g to 53 g) and achieved earlier due to the closer coupling of the belt system. Chest contact with the steering wheel is also eliminated. Chest deflection is reduced from 55 mm to 36 mm. Belt loading is increased but occurs earlier as a result of closer coupling, so that the belt system is absorbing the occupant forces rather than the interior fittings such as the steering wheel and dashboard. This is further demonstrated by the reduction in pelvic deceleration and femur loads.

3.4.4 Test X00B0009

In this test, the set up evaluated the effects of the webbing clamp retractor with low elongation webbing (7%), buckle pretensioner and facebag (30 litre airbag).

The airbag system was a prototype made up from Autoliv "standard" components but without a cover. This method was adopted so that the standard steering wheel could be modified to accept the airbag system without affecting the characteristics of the steering control such as steering wheel reach. The airbag was folded as normal practice and held in position by strong tape. The difference in performance between a properly designed and developed cover and the tape is negligible.

Using the concept of 'Residual Deformation' (10), the following procedure was used to determine the facebag ignition time:

- plot the displacement curve of the vehicle compartment (second integral of the deceleration curve)
- plot the displacement curve of a 'free flying mass' (FFM) for both the original vehicle and sled impact velocities
- determine the time where the difference between the FFM and compartment displacement equals 200 mm. This represents the time when the facebag must have completed inflation
- subtract the inflation time (25 milliseconds for facebag) from this figure to give the latest triggering time to start inflation of the facebag
- an allowance of a further 5 milliseconds was then included to provide additional clearance between the facebag and the dummy's head. This was not considered to affect injury criteria values.

This resulted in an airbag ignition time of 25 milliseconds after "time zero" (impact) to permit inflation to occur before the occupant's head contacts the bag. The high speed film of the sled test showed that the bag was completely inflated by 48 milliseconds and face contact occurred at about 55 milliseconds. Head penetration into the airbag was about 180 mm at about 82 milliseconds.

Head deceleration was reduced due to the airbag cushioning effect from a maximum of 210 g to 68 g and the 3 millisecond clip level from 73 g to 68 g. HIC values do not show a dramatic improvement over the baseline sled test as the smoother deceleration curve for a longer duration influences the HIC calculation. However, this test provided lower HIC values when compared with test X00B0008 which had the same belt system but the TRRL wheel instead of the facebag.

Chest injury criteria demonstrated a marked improvement over the basic restraint system in deceleration level and deflection. However, when compared with the TRRL wheel, the deceleration level is increased possibly due to the aggressive tendencies of the airbag between the chest and the steering wheel.

As expected the airbag had little or no effect on the lower torso injury criteria to those of the same belt system in test X00B0008.

3.4.5 Test X00B0010

This test was to examine the effect of an facebag as a supplement to the standard belt system.

The head decelerations were effectively reduced but with little change in HIC values. Actual crash tests would be expected to demonstrate greater benefits.

Airbag aggression is demonstrated by higher chest deceleration but lower deflection. The static steering wheel would accentuate this effect because it is set at the intruded position for the sled series.

As stated previously, the lower torso injury criteria are not affected and gave similar results to the baseline sled test X00B0003.

3.4.6 Test X00B0011

This was a repeat of test X00B0005 but with reinforced seat mounting.

The TRRL steering wheel reduced the head deceleration levels compared with the baseline test although the HIC calculation was higher. Again, this is due to lower overall head deceleration but over a longer period.

The webbing clamp retractor with low elongation webbing reduced lower torso injury criteria in that pelvic deceleration and femur loads were both lower than the baseline test X00B0003.

3.5 Airbag Discussion

Although the airbag with a standard seat belt system provides benefit in head injury reduction, the benefits are increased when the seat belt system is also optimised.

When considering the two tests with an airbag, there are some interesting characteristics:

	X00B0009 (WC/PT)	X00B0010 (Std belt)
Head Penetration	184 mm	205 mm
Min. S/wheel clearance	142 mm	105 mm
Max. deceleration	69 g	74 g
Max. bag pressure during head contact	44 kPa	55 kPa

Assuming the same bag performance, the lower penetration of the head into the airbag in test X00B009 would be expected to result in higher head decelerations but this is not the case. The reason for the observed behaviour is that the contact velocity of the head is less with the modified seat belt system than with the standard belt system.

In test X00B0010, this higher head velocity causes the bag pressure to increase slightly during head contact (11 kPa) due to the squashing effect of the airbag between the steering wheel rim and the dummy's head.

3.6 Discussion of Sled Test Results

The sled pulse was set up to simulate the mean deceleration of the vehicle in the crash test. Because there is no rigid connection between the dummy and the vehicle structure, the dummy will respond to the mean deceleration rather than the peaks and troughs of short duration in the actual crash pulse.

The sled pulse also tends to be of shorter duration on the decay side than the vehicle pulse as the type of sled used has little rebound effect. However, the velocity change of the sled and the car crash show good correlation.

The seats supplied by the manufacturer were not the same as those on the original test vehicle (BT 237). The seats were the top specification unit and trimmed in a velour covering. Autoliv noted that this would probably have some effect on the results but were not been able to quantify this. The seats also had a height adjustment which was set at the second position from the highest for all tests.

During the sled series, it was found that the webbing clamps and buckle pretensioners increased the loads on their anchorages which resulted in failures of components in the seat adjuster and adjustable upper torso anchor assemblies in some tests. To overcome this, the seat adjusters were welded in place and the seat anchorage points strengthened. In addition, the centre anchorage point was used to mount the sash guide on the B-pillar instead of the adjustable upper torso anchorage slider assembly.

Lower injury criteria would be expected in barrier crash tests as sled tests cannot replicate the dynamic response of the vehicle. The steering column, steering wheel, instrument panel were placed in the positions determined from the high speed film of the baseline tests. The toepan area was built up to simulate the intruded condition.

As the test buck had to experience many tests, it was stiffened to avoid destroying the location points for the components of the restraint system to maintain test to test consistency. This stiffening reduces structural flexibility which can affect the belt loads, dummy kinematics and consequently injury criteria when compared with actual vehicle crash tests.

Table B5
FORS Crash Test Program — Phase 2
Sled test component configuration matrix

Passenger Test No	Component Configuration	Comment
X00B0001	Seat in mid position, with adjustable shoulder anchorage at mid position, original belt system	Inboard seat adjuster unlatched — correlates with crash test
X00B0002	Seat welded in mid position, with adjustable shoulder anchorage at mid position, original belt system	Inboard seat mounting pulled out of bolt
X00B0004	Seat welded in mid position, with adjustable shoulder anchorage at mid position, webbing clamp retractor, seat mounting point reinforced	Adjustable shoulder anchorage fractured, headcontact with dashboard
X00B0006	Seat welded in mid position, fixed mid position shoulder anchorage used, webbing clamp retractor, seat mounting point reinforced	No head contact, belt reel out 18 mm
X00B0007	Seat welded in mid position, fixed mid position shoulder anchorage used, seat mounting point reinforced, webbing clamp retractor, buckle pretensioner	No head contact, belt reel out 14 mm
Driver Test No	**Component Configuration**	**Comment**
X00B0003	Seat welded in mid position, with adjustable shoulder anchorage at mid position, original belt system	Head contact with steering wheel, chin and lip contact with hub
X00B0005	Seat welded in mid position, fixed mid position shoulder anchorage used, webbing clamp retractor, TRRL steering wheel	Head contact with hub, chin and lip contact, belt reel out 6 mm, inboard seat mounting pulled out of bolt
X00B0008	Seat welded in mid position, fixed mid position shoulder anchorage used, webbing clamp retractor, TRRL steering wheel, buckle pretensioner, seat mounting point reinforced	Belt reel out 19 mm
X00B0009	Seat welded in mid position, fixed mid position shoulder anchorage used, webbing clamp retractor, buckle pretensioner, Eurobag, seat mounting point reinforced	Belt reel out 22 mm
X00B0010	Seat welded in mid position, fixed mid position shoulder anchorage used, seat mounting point reinforced, original belt system, Eurobag	Belt reel out 42 mm
X00B0011	Seat welded in mid position, fixed mid position shoulder anchorage used, seat mounting point reinforced, webbing clamp retractor, TRRL steering wheel	Belt reel out 20 mm
Notes:	(1) seat height adjuster in 2nd position from top for all tests (2) seat back angle 25 degrees for all tests	

Source: Autoliv, "Report on Sled Tests on Ford Laser — Evaluation of Modified Belt System, Energy Absorbing Steering Wheel and Eurobag" for the Federal Office of Road Safety.

Table B6

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	1,8	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	884	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	7,8	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.

Source: Autoliv, "Report on Sled Tests on Ford Laser — Evaluation of Modified Belt System, Energy Absorbing Steering Wheel and Eurobag" for the Federal Office of Road Safety.

4 Discussion on Phase 2 Optimisation Program

It should be remembered that the Phase 2 work 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.

The baseline sled test did not show good correlation with the Phase 1 crash test mainly in the areas of HIC and femur loads. This was due to the change in dummy kinematics in sled tests caused by the inability to reproduce the dynamic intrusion experienced in crash tests. Better correlation could have been achieved if more sled tests were carried out to tune the test rig. Unfortunately, this was not possible within the scope of this project. However, Autoliv considered that it provided a reasonable basis to examine the effect of changes to the restraint system on dummy kinematics.

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 which can in turn modify the effects of the system components described.

Autoliv also note that the components tested have not been fully optimised for the vehicle and a comprehensive development program would be necessary before introduction into the marketplace.

A complete optimisation program would take these factors into consideration as well as the other crash situations outside any legislative requirements. In addition, different occupant sizes and seating positions would also have to be accounted for.

This work demonstrates, primarily, the potential for improving occupant protection by properly engineering a range of emerging restraint technology into a vehicle.

5 Outcome of Phase 2 Optimisation Program

The computer simulation showed good correlation to Phase 1 crash test.

The sled tests showed similar trends to the computer simulation in respect to:

- reduced head decelerations in the passenger resulting from the elimination of contact with the dashboard.
- reduced head and chest decelerations in the driver when a facebag was used
- reduced lower torso injury criteria for both driver and passenger when seat belt buckle pretensioner and webbing clamp retractor are used.

In addition, the TRRL energy absorbing steering wheel indicates the ability to reduce head deceleration and chest deflection in the driver.

Based on this work, the prototype components which were to be fitted the Phase 3 crash vehicles were set up in the following manner:

- The airbag triggering time was set to be 25.2 milliseconds after impact.
- The buckle pretensioner triggering time was set at 18 milliseconds.

Part C

Phase 3
Crash Tests with Enhanced Restraints Systsems

Phase 3 — Crash Tests with Enhanced Restraint Systems

The aim of the Phase 3 crash tests was to follow on from the Phase 2 work to look at the injury mitigation potential of the three restraint system combinations in real crash conditions.

1 Test Procedure

1.1 Introduction

The test procedures used were the same as those in the Phase 1 crash tests (see Part A section 1).

1.2 Test Vehicles

The Ford Lasers used were KH models which is a facelifted version of the KF model used in the Phase 1 tests. There were no design changes which would have affected crash performance.

The specifications of the test vehicles were the same as those of the vehicle used in the Phase 1 test, viz GL Hatchbacks with automatic transmission, air conditioning and manual steering.

The vehicles were selected at random from fleet vehicles delivered to the Federal Government's Department of Administrative Services so as to assure that the vehicles were representative of series production. Each vehicle was uniquely marked and their Vehicle Identification Numbers (VINs) were recorded.

The Vehicles were marked with a Barrier Test (BT) number. BT numbers used were: 252, 253 and 258.

The three test vehicles had the following VINs and restraint system combinations:

Test No	VIN	Restraint Combination
BT 252	6FPAAAUK4RMM94325	*Driver's side* TRRL energy absorbing steering wheel, webbing clamp retractor with 7% elongation webbing, buckle pretensioner
		Passenger's side webbing clamp retractor with 7% elongation webbing, buckle pretensioner
BT 253	6FPAAAUK4RMM94324	*Driver's side* facebag, standard (original equipment) restraint

		Passenger's side standard (original equipment) restraint
BT 258	6FPAAAUK4RMM94326	*Driver's side* facebag, webbing clamp retractor with 7% elongation webbing, buckle pretensioner
		Passenger's side webbing clamp retractor with 7% elongation webbing, buckle pretensioner

1.3 Vehicle Preparation

The vehicles were prepared in the same way as those for the Phase 1 tests (see Part A section 1.4).

In addition, the following modifications were made to account for the extra loadings put on the restraint system anchorages by the buckle pretensioners and webbing clamp retractors:

- The seat adjusters were welded in place after they were adjusted to their test positions.
- The adjustable upper torso anchorage assembly was removed and the standard (fixed) mid-point anchorage was used for both driver and passenger in tests BT 252 and BT 253. In BT 258 the passenger's sash guide was mounted on the uppermost anchorage point to examine the effect on upper torso dummy kinematics. The mid-point anchorage was used on the driver's side in BT 258.

For tests BT 253 and BT 258, the hub area of the standard Laser steering wheel was scalloped out and a frame made up with three support arms to mount the airbag module. The end of the steering column shaft was shortened to provide clearance for the airbag module, however the standard reach of the steering wheel was maintained.

Appendix 8 shows the various component configurations tested together with post-test photographs.

1.4 Instrumentation

The instrumentation set-up was the same as for the Phase 1 tests (see Part A section 2.3) For these tests, the following additional equipment was used:

- An extra on-board camera to film deployment of the buckle pretensioner.
- Sensors to monitor the deployment time of the buckle pretensioner and airbag.
- A pressure transducer to monitor airbag pressure.

2 Phase 3 Test Results

This section provides the results of the test series together with an indication of the dummy contact points with the vehicle interior which may have caused the dummy response recorded.

This section also includes a discussion of the effect on dummy kinematics of the three restraint systems tested and the correlation with the Phase 2 restraint optimisation program.

Charts showing individual injury criteria by type are contained in Table C2.1. The Dummies' pelvic decelerations and seat belt webbing loads are listed in Table C2.2. Bar charts comparing the barrier test vehicles for each injury criteria are contained in Appendix 10.

2.1 Test Vehicle Speed

The requirements of FMVSS 208 are that the vehicle impact speed be 47.3 ± 0.8 km/h (range of 46.5 to 48.1). The speeds at impact are detailed below:

Vehicle	Speed km/h
BT 252	47.5
BT 253	47.7
BT 258	46.8

The crash pulses for each test vehicle are given in Appendix 9. It should be noted that although the vehicles were of consecutive build, each crash pulse is slightly different.

2.2 Head Injury Criteria (HIC)

The HIC values ranged from 547 to 598 for the Driver's side, and from 408 to 871 for the Passenger's side.

There was no Passenger head contact with the dashboard in the two tests incorporating webbing clamp retractors and buckle pretensioners, BT 252 and BT 258. The 15 msec HIC figures of 253 and 338 respectively provide an indication of the improvement due to the elimination of head contact. The higher value for BT 258 is probably due to the higher upper torso anchorage point allowing more upper torso movement.

2.3 Chest Deceleration

The Driver's chest decelerations were between 39 g and 57 g while the Passenger figures were between 40 g and 48 g.

The figures were similar for Driver and Passenger in test BT 252 probably due to the cushioning effect of the TRRL steering wheel on the chest of the Driver.

The high figure for the Driver in test BT 253 (facebag and standard restraint) was probably caused by the stiffness of that part of the airbag which was squashed between the steering wheel rim and the chest. This effect is not evident in BT 258 where the webbing clamp retractor and buckle pretensioner provided closer coupling of the dummy to the vehicle crash pulse and limited forward excursion. The same effect was observed in the Phase 2 sled tests with the same restraint combinations.

2.4 Chest Deflection

The Driver's chest deflections were between 34.4 mm and 40.0 mm while the Passenger figures were between 31.4 mm and 34.0 mm.

2.5 Femur Loadings

The Driver and Passenger femur loads were reduced on the two test vehicles fitted with webbing clamp retractors and buckle pretensioners. This is due to the reduced excursion and changes in lower torso kinematics. This is also demonstrated by the load vs time traces which indicate that the maximum loads are caused by the toepan intrusion whereas in vehicles fitted with the standard restraint system the (higher) maximum loads are caused by leg strike with the under-dash area.

2.6 Lost Data

2.6.1 Test BT 252

In test BT 252, the z-axis accelerometer measuring the driver's pelvic deceleration was damaged which resulted in this parameter not being reported.

2.6.2 Test BT 258

In test BT 258, a spurious signal of constant level appeared 15.5 milliseconds after impact.

This caused the airbag to trigger at this point instead of the programmed 25.2 millisecond deployment time.

In addition, this spurious signal caused a zero offset in most of the transducers in both dummies with the exception of the right and left hand passenger femur loads, and the chest deflection of the driver. The transducers mounted on the vehicle itself and the seat belt transducers were unaffected.

At about 60 milliseconds after impact, the power supply cable to all transducers connected to Control Box 4 broke. This resulted in a breakdown of the data of the transducers connected to the control box, viz both driver femur loads and the driver seat belt loads. None of this data was recoverable and has not been reported.

At about 80 milliseconds after impact, a malfunction occurred in the transducer measuring the right hand passenger femur load. It was considered that the passenger femur load was recoverable because maximum loading had occurred prior to the equipment malfunction.

The offset caused by the spurious signal was corrected for and these figures have been provided in this report. It is considered that a high level of confidence can be placed on these corrected results.

2.7 Discussion of Phase 3 Results

The computer modelling, sled tests and crash testing of the three vehicles fitted with combinations of emerging safety technology showed good correlation with respect to their effect on dummy kinematics, within the bounds of test variability (11).

The dummy kinematics observed in the Phase 3 crash tests correlated well with those in the Phase 2 sled tests. The difference in injury criteria values results from the effect on the dummy response caused by dynamic intrusion in a real crash against the static intruded position used for the same components in the sled tests.

The webbing clamp retractor/buckle pretensioner combination changes the occupant upper torso kinematics in such a way as to promote a head strike in the steering wheel hub area which is likely to increase HIC values. However, this can be addressed by the fitment of an airbag or a steering wheel with an energy absorbing hub such as the TRRL wheel. This was confirmed in the Phase 3 tests.

The webbing clamp retractor/buckle pretensioner combination also has the potential of reducing chest deceleration levels by closer coupling of the occupant to the vehicle crash pulse.

The facebag with standard restraint system has the potential to reduce HIC values but there did not appear to be a corresponding reduction in chest deceleration.

The webbing clamp retractor/buckle pretensioner combination also has the potential to reduce femur loads because of reduced excursion. This is also demonstrated by the load vs time traces which indicate that with this combination fitted, the maximum loads were caused by toepan intrusion whereas in vehicles fitted with the standard restraint system the maximum loads are caused by leg strike with the under-dash area.

The buckle pretensioner has potential as an anti-submarining countermeasure. This is demonstrated by the reduced pelvic deceleration and improvement in the lap belt angles after deployment which have the effect of reducing the possibility of the lap belt riding over the iliac crest and into the abdominal cavity.

The full frontal crash test is only one of the several crash modes usually undertaken by vehicle manufacturers during model development in optimising the restraint system to encompass real life crash situations. Table C2.3 contains a list of the various crash modes and conditions which might be used when developing a seat belt buckle pretensioner and airbag.

Table C2.1
FORS Crash Test Program — Phase 3
Injury Criteria Results

Test Vehicle	BT 237(Ph1) Standard Restraint		BT 252 TRRL/WC/PT		BT 253 Airbag/ std restraint		BT 258 Airbag/WC/PT	
	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass
Head Injury Criteria (HIC 36)	1012	860	598	408*	553	871	547	661*
Head Injury Criteria (HIC 15)	719	841	484	253	402	741	424	338
Chest Decel (g)- 3msec	59.4	40	39	40	57	48	42	42
Chest Deflec (mm)	42.7	29.1	34.4	34.0	40.0	31.4	39.9	N/A#
Femur Loads (kN)								
Left Leg	4.2	1.8	2.0	1.5	3.6	1.9	N/A#	2.6
Right Leg	6.8	2.9	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 & Road Research Laboratory
WC Webbing clamp retractor with 7% elongation webbing
PT Seat belt buckle pretensioner

Notes:
(1) Seat adjusters welded up on Phase 3 vehicles.
(2) On BT 252 and 253, middle position on B-pillar used for upper torso anchorage (UTA) for driver and passenger.
(3) On BT 258, middle UTA position used for driver, upper UTA position used for passenger.

Table C2.2

FORS Crash Test Program — Phase 3
Seat belt loads and pelvic deceleration

Test Vehicle	BT 237(Ph1) Standard Restraint		BT 252 TRRL/WC/ PT		BT 253 Airbag/ std restraint		BT 258 Airbag/WC/ PT	
	Driv	Pass	Driv	Pass	Driv	Pass	Driv	Pass
Sash Belt Loads (kN)								
Upper	7.0	6.8	9.2	7.7	6.6	6.8	N/A#	8.8
Lower	10.5	11.0	13.8	10.3	8.8	10.5	N/A#	9.7
Lap Belt Loads (kN)								
Inner	8.8	11.2	13.6	13.8	9.7	12.8	N/A#	13.4
Outer	7.9	11.0	7.0	4.6	4.8	6.0	N/A#	5.6
Pelvic Decel. (g)	70.0	40.0	N/A*	36.5	72.0	48.4	65.9	41.6

* Z-axis accelerometer damaged
\# Data corrupted and unrecoverable
TRRL Energy absorbing steering wheel developed by UK Transport & Road Research Laboratory
WC Webbing clamp retractor with 7% elongation webbing
PT Seat belt buckle pretensioner

Notes:
(1) Seat adjusters welded up on Phase 3 vehicles.
(2) On BT 252 and 253, middle position on B-pillar used for upper torso anchorage (UTA) for driver and passenger.
(3) On BT 258, middle UTA position used for driver, upper UTA position used for passenger.

Table C2.3

FORS Crash Test Program — Phase 3
Examples of crash modes for developing buckle pretensioner and facebag

Crash pulse requirement for buckle pretensioner

Crash type	Velocity (km/h)	Firing condition
Zero degree	15	No Fire
	25	"Grey"
	35	Fire
	50	Fire
	56	Fire
Offset	35	To be determined
	50	
30 degree	35	"Grey"
	50	Fire
Pole	35	"Grey"
	50	Fire
Under-ride	35	"Grey"
	50	Fire
Rough Road	To be determined	No Fire

Crash pulse requirement for facebag

Crash type	Velocity (km/h)	Firing condition
Zero degree	25	No Fire
	30	"Grey"
	35	Fire
	50	Fire
	56	Fire
Offset	35	To be determined
	50	
30 degree	35	"Grey"
	50	Fire
Pole	35	"Grey"
	50	Fire
Under-ride	35	"Grey"
	50	Fire
Rough Road	To be determined	No Fire
Column adjustment	To be determined	No Fire

'Grey' means firing condition will depend on vehicle model design (restraint system, crumple characteristics)

3 Outcome of Phase 3 Crash Tests

This work has provided an indication of the likely improvements which these restraint combinations might achieve. It has highlighted the amount of work required to engineer these improvements into a production vehicle. It also indicates the additional work required to fully optimise the systems considered in this report.

Both the airbag and the energy absorbing TRRL steering wheel have the potential to reduce head injuries significantly.

This injury mitigation potential is extended to include chest and leg injuries when these devices are used in conjunction with seat belt restraint improvements such as webbing clamp retractors and buckle pretensioners.

The Phase 3 crash tests highlighted one aspect of test variability in that, although the three test vehicles were built consecutively, they all exhibited different crash pulses.

This crash test program has indicated that significant injury mitigation is possible if a current vehicle model is re-developed to comply with the injury parameters set out in US Federal Motor Vehicle Safety Standard 208 for full frontal impact protection with the test dummies restrained by lap sash seat belts.

Part D

Summary of FORS Crash Test Program

1 Introduction

The three elements of the FORS crash test program were:

Phase 1

Conduct a series of full frontal crash tests at a nominal speed of 48 km/h on seven top-selling Australian mass produced vehicles. The test procedure used was that specified in the United States Federal Motor Vehicle Safety Standard 208 (FMVSS 208), with 'Hybrid III' dummies restrained in outboard front seating positions.

Phase 2

Autoliv, Germany to analyse the crash data from one of the vehicle models used in Phase 1 to develop three restraint systems using combinations of emerging safety technology including, energy absorbing steering wheels, seat belt buckle pretensioners, seat belt webbing clamp retractors and facebags. The development work included the use of computer simulation techniques and sled tests to optimise the restraint system combinations for a 48 km/h full frontal barrier crash condition.

Phase 3

To crash test three vehicles fitted with the three enhanced restraint systems using the same test procedure as Phase 1 to provide an indication of their injury mitigation potential under real crash conditions.

2 Discussion of FORS Crash Test Program

It is important to note that this program was carried out to evaluate possible new safety standards for Australian vehicles. Due to test to test variability, the test results from this program do not form a basis for drawing sustainable comparison of the safety performance of each vehicle. Test variability could be in the order of 20% or more.

It is also 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.

This work demonstrated, primarily, the potential for improving occupant protection by the incorporation of various new safety components.

The computer modelling, sled tests and crash testing of the three vehicles fitted with combinations of emerging safety technology showed good correlation with respect to their effect on dummy kinematics, within the bounds of test variability.

Computer simulation and sled tests are valuable tools in developing a restraint system for a particular vehicle model. The main advantage is the ability to discover the relative effects of changes to the restraint system and be able to predict its performance in a real crash condition with a reasonable level of confidence. The advantages also extend to reduced testing costs and turnaround times between tests.

However, the actual performance of the vehicle system in real crash conditions can only be determined in expensive barrier crash tests.

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 which can in turn modify the effects of the system components described. In addition, different occupant sizes and seating positions would also have to be accounted for.

A complete optimisation program to develop a production-ready passenger restraint system would take these factors into consideration as well as the other crash situations outside any legislative requirements.

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 of the various elements to be optimised to achieve the best safety outcome.

3 Summary of FORS Crash Test Program Results

3.1 Outcome of Phase 1 Crash Tests

The vehicle models used in the Phase 1 crash tests were built to conform with the current Australian Design Rules for vehicle safety which are commensurate with requirements in Europe and Japan. There were no unexpected structural failures observed during the crash tests.

The results demonstrated that there is room for improvement and 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.

Generally the HIC value was lower for the Passenger than for the Driver. Head contact with steering assembly, and also the dashboard 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. In one vehicle, passenger head contact with the glove compartment lid also occurred during the crash sequence.

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. There were two cases of high loadings caused by contact onto hard objects in the underdash area.

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. Only in the case of the driver's left knee in test BT 235 was significant injury likely to occur.

3.2 Outcome of Phase 2 Optimisation Program

The computer simulation showed good correlation with the Phase 1 crash test.

The sled tests showed similar trends to the computer simulation in respect to:

- reduced head decelerations in the passenger resulting from the elimination of contact with the instrument panel.
- reduced head and chest decelerations in the driver when a facebag was used
- reduced lower torso injury criteria for both driver and passenger when seat belt buckle pretensioner and webbing clamp retractor are used.

In addition, the TRRL energy absorbing steering wheel indicates the ability to reduce head deceleration and chest deflection in the driver.

The triggering times for the airbag and buckle pretensioner which were to be fitted the Phase 3 crash vehicles were derived from this work.

3.3 Outcome of Phase 3 Crash Tests

Both the airbag and the energy absorbing TRRL steering wheel demonstrated the potential to reduce head injuries.

This injury mitigation potential is extended to include chest and leg injuries when these devices are used in conjunction with seat belt restraint improvements such as webbing clamp retractors and buckle pretensioners.

4 Conclusion from FORS 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 which are commensurate with requirements in Europe and Japan. There were no unexpected structural failures observed during the crash tests.

This program has shown that new safety technology such as seatbelt tensioners, webbing clamp retractors, energy absorbing steering wheels and driver side airbags have the potential to bring about reductions in driver and passenger injuries in crashes.

This work has provided an indication of the likely improvements which these restraint combinations might achieve. This research program has also shown that the use of some of these devices in isolation may not achieve any injury mitigation and can, in some cases, increase the likelihood of injury.

This program has highlighted the amount of work required to engineer these improvements into a production vehicle. It also indicates the additional work required to fully optimise the systems considered in this report.

Therefore it is important to stress that any regulatory standard to improve frontal impact protection should aim at injury mitigation and a means to measure it, rather than the specification of particular safety components.

This crash test program has indicated that significant injury mitigation is possible if a current vehicle model is re-developed to comply with the injury parameters set out in US Federal Motor Vehicle Safety Standard 208 for full frontal impact protection with the test dummies restrained by lap sash seat belts.

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.

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Appendix 1

US Federal Motor Vehicle Safety Standard 208 Extracts

Appendix 1

This appendix consists of extracts from US Federal Motor Vehicle Safety Standard (FMVSS) 208 — Occupant Crash Protection which describe the test procedures used in this crash series.

The US regulations allow the use of either Hybrid II (Part 572, Subpart B test dummy) or the more advanced Hybrid III (Part 572, Subpart E test dummy) for certifying vehicles to FMVSS 208.

In the case of the FORS test series, the more biofidelic Hybrid III test dummies were used, therefore reference should be made to the Subpart E dummies in the extract below.

In addition, only those sections covering frontal impact testing of passenger cars should be referred to.

Extract from FMVSS 208

S8. Test conditions

S8.1 General conditions. The following conditions apply to the frontal, lateral, and rollover tests.

S8.1.1 Except as provided in paragraph (c) of this section, the vehicle, including test devices and instrumentation is loaded as follows:

(a) Passenger cars. A passenger car is loaded to its unloaded vehicle weight plus its rated cargo and luggage capacity weight, secured in the luggage area, plus the weight of the necessary anthropomorphic test devices.

(b) Multipurpose passenger vehicles, trucks, and buses. A multipurpose passenger vehicle, truck, or bus is loaded to its unloaded vehicle weight plus 300 points or its rated cargo and luggage capacity weight, whichever is less, secured in the load carrying area and distributed as nearly as possible in proportion to its gross axle weight ratings, plus the weight of the necessary anthropomorphic test devices. For the purposes of 8.1.1, unloaded vehicle weight does not include the weight of work-performing accessories. Vehicles are tested to a maximum unloaded vehicle weight of 5,500 pounds.

(c) Fuel system capacity. With the test vehicle on a level surface, pump the fuel from the vehicle's fuel tank and then operate the engine until it stops. Then, add Stoddard solvent to the test vehicle's fuel tank in an amount which is equal to or less than 92 and not more than 94 percent of the fuel tank's useable capacity stated by the vehicle's manufacturer. In addition, add the amount of Stoddard solvent needed to fill the entire fuel system from the fuel tank through the engine's induction system.

(d) Vehicle test attitude. Determine the distance between a level surface and a standard reference point on the test vehicle's body, directly above each wheel opening, when the vehicle is in its "as delivered" condition. The "as delivered" condition is the vehicle as received at the test site, with 100 percent of all fluid capacities and all tires inflated to the manufacturer's specifications as listed on the vehicle's tire placard. Determine the distance between the same level surface and the same standard reference points in the vehicle's "fully loaded condition". The "fully loaded condition" is the test vehicle loaded in accordance with S8.1.1 (a) or (b), as applicable. The load placed in the cargo area shall be centered over the longitudinal centerline of the vehicle. The pretest vehicle attitude shall be equal to either the as delivered or fully loaded attitude or between the as delivered attitude and the fully loaded attitude.

S8.1.2 Adjustable seats are in the adjustment position midway between the forwardmost and rearmost positions, and if separately adjustable in a vertical direction, are at the lowest position. If an adjustment position does not exist midway between the forwardmost and rearmost positions, the closest adjustment position to the rear of the midpoint is used.

S8.1.3 Place adjustable seat backs in the manufacturer's nominal design riding position in the manner specified by the manufacturer. Place any adjustable anchorages at the manufacturer's nominal design position for a 50th percentile adult male occupant. Place each adjustable head restraint in its highest adjustment position. Adjustable lumbar supports are positioned so that the lumbar support is in its lowest adjustment position.

S8.1.4 Adjustable steering controls are adjusted so that the steering wheel hub is at the geometric centre of the locus it describes when it is moved through its full range of driving positions.

S8.1.5 Movable vehicle windows and vents are, at the manufacturer's option, placed in the fully closed position.

S8.1.6 Convertibles and open-body type vehicles have the top, if any, in place in the closed passenger compartment configuration.

S8.1.7 Doors are fully closed and latched but not locked.

S8.1.8 Anthropomorphic test dummies.

S8.1.8.1 The anthropomorphic test dummies used for evaluation of occupant protection systems manufactured pursuant to applicable portions of paragraphs S4.1.2, 4.1.3, and S4.1.4 shall conform to the requirements of Subpart B of Part 572 of this Chapter.

S8.1.8.2 Anthropomorphic text devices used for the evaluation of occupant protection systems manufactured pursuant to applicable portions of paragraphs S4.1.2, S4.1.3 and S4.1.4 shall conform to the requirements of Subpart E of Part 572 of this Chapter.

S8.1.9.1 Each Part 572, Subpart B test dummy specified in S8.1.8.1 is clothed in formfitting cotton stretch garments with short sleeves and midcalf length pants. Each foot of the test dummy is equipped with a size 11EE shoe which meets the configuration size, sole, and heel thickness specifications of MIL-S 131192 and weights 1.25 SYMBOL 177 \f "Symbol"0.2 pounds.

S8.1.9.2 Each Part 572, Subpart E test dummy specified in S8.1.8.2 is clothed in formfitting cotton stretch garments with short sleeves and midcalf length pants specified in drawings 78051-292 and -293 incorporated by reference in Part 572, Subpart E of this Chapter, respectively or their equivalents. A size 11EE shoe specified in drawings 78051-294 (left) and 78051-295 (right) or their equivalents is placed on each foot of the test dummy.

S8.1.10 Limb joints are set at lg, barely restraining the weight of the limb when extended horizontally. Leg joints are adjusted with the torso in the supine position.

S8.1.11 Instrumentation does not affect the motion of dummies during impact or rollover.

S8.1.12 Temperature of the test dummy.

S8.1.12.1 The stabilized temperature of the test dummy specified by S8.1.8.1 is at any level between 66 degrees F and 78 degrees F.

S8.1.12.2 The stabilized temperature of the test dummy specified by S8.1.8.2 is at any level between 69 degrees F and 72 degrees F.

S11 Positioning procedure for the Part 572 Subpart E Test Dummy

Position a test dummy, conforming to Subpart E of Part 572 of this Chapter, in each front outboard seating position of a vehicle as specified in S11.1 through S11.6. Each test dummy is restrained in accordance with the applicable requirements of S4.1.2.1, 4.1.2.2 or S4.6.

S11.1 Head. The transverse instrumentation platform of the head shall be horizontal within 1/2 degree. To level the head of the test dummy in vehicles with upright seats with non-adjustable backs, the following sequences must be followed. First adjust the position of the H point within the limits set forth in S11.4.3.1 to level the transverse instrumentation platform on the head of the test dummy. If the transverse instrumentation platform of the head is still not level, then adjust the pelvic angle of the test dummy within the limits provided in S11.4.3.2 of the standard. If the transverse instrumentation platform of the head is still not level, then adjust the neck bracket of the test dummy the minimum amount necessary to ensure that the transverse instrumentation platform of the head is horizontal within 1/2 degree.

S11.2 Arms

S11.2.1 The driver's upper arms shall be adjacent to the torso with the centrelines as close to a vertical plane as possible.

S11.2.2 The passenger's upper arms shall be in contact with the seat back and the sides of torso.

S11.3 Hands

S11.3.1 The palms of the driver test dummy shall be in contact with the outer part of the steering wheel rim at the rim's horizontal centreline. The thumbs shall be over the steering wheel rim and shall be lightly taped to the steering wheel rim so that if the hand of the test dummy is pushed upward by a force of not less than 2 pounds and not more than 5 pounds, the tape shall release the hand from the steering wheel rim.

S11.3.2 The palms of the passenger test dummy shall be in contact with outside of thigh. The little finger shall be in contact with the seat cushion.

S11.4 Torso

S11.4.1 In vehicles equipped with bench seats, the upper torso of the driver and passenger test dummies shall rest against the seat back. The midsagittal plane of the driver dummy shall be vertical and parallel to the vehicle's longitudinal centreline, and pass through the centre of the steering wheel rim. The midsagittal plane of the passenger dummy shall be vertical and parallel to the vehicle's longitudinal centreline and the same distance from the vehicle's longitudinal centreline as the midsagittal plane of the driver dummy.

S11.4.2 In vehicles equipped with bucket seats, the upper torso of the driver and passenger test dummies shall rest against the seat back. The midsagittal plane of the driver and the passenger dummy shall be vertical and shall coincide with the longitudinal centreline of the bucket seat.

S11.4.3 Lower Torso

S11.4.3.1 H-point. The H-point of the driver and passenger test dummies shall coincide within 1/2 inch in the vertical dimension and 1/2 inch in the horizontal dimension of a point 1/4 inch below the position of the H-point determined by using the equipment and procedures specified in SAE J826 (Apr 80) except that the length of the lower leg and thigh segments of the H-point machine shall be adjusted to 16.3 and 15.8 inches, respectively, instead of the 50th percentile values specified in Table 1 of SAE J826.

S11.4.3.2 Pelvic angle. As determined using the pelvic angle gage (GM drawing 78051-532 incorporated by reference in Part 572, Subpart E of this chapter) which is inserted into the H-point gaging hole of the dummy, the angle measured from the horizontal on the 3 inch flat surface of the gage shall be 22 1/2 degrees plus or minus 2 1/2 degrees.

S11.5 Legs

S11.5.1 The legs of the driver and passenger test dummy shall be placed as provided in S11.5.2 or, at the option of the vehicle manufacturer until September 1, 1991, as provided in S10.1.1 for the driver and S10.1.2 for the passenger, except that the initial distance between the outboard knee clevis flange surfaces shall be 10.6 inches for both the driver and the passenger rather than 14 1/2 inches as specified in S10.1.1(a) for the driver and 11 3/4 inches as specified in S10.1.2.1(a) and S10.1.2.2(a) for the passenger.

S11.5.2 The upper legs of the driver and passenger test dummies shall rest against the seat cushion to the extent permitted by placement of the feet. The initial distance between the outboard knee clevis flange surfaces shall be 10.6 inches. To the extent practicable, the left leg of the driver dummy and both legs of the passenger dummy shall be in vertical longitudinal planes. To the extent practicable, the right leg of the driver dummy shall be in a vertical plane. Final adjustment to accommodate placement of feet in accordance with S11.6 for various passenger compartment configuration is permitted.

S11.6 Feet. The feet of the driver test dummy shall be positioned in accordance with S10.1.1(b) and (c) of this standard. The feet of the passenger test dummy shall be positioned in accordance with S10.1.2.1(b) and (c) or S10.1.2.2(b) and (c) of this standard, as appropriate. (SEE BELOW)

S10.1.1 Driver position placement.

(b) Rest the right foot of the test dummy on the undepressed accelerator pedal with the rearmost point of the heel on the floor pan in the plane of the pedal. If the foot cannot be placed on the accelerator pedal, set it initially perpendicular to the lower leg and place it as far forward as possible in the direction of the pedal centreline with the rearmost point of the heel resting on the floor pan. Except as prevented by contact with a vehicle surface, place the right leg so that the upper and lower leg centrelines fall, as close as possible, in a vertical plane without inducing torso movement.

(c) Place the left foot on the toeboard with the rearmost point of the heel resting on the floor pan as close as possible to the point of intersection of the planes described by the toeboard and the floor pan and not on the wheelwell projection. If the foot cannot be positioned on the toeboard, set it initially perpendicular to the lower leg and place it as far forward as possible with the heel resting on the floor pan. If necessary to avoid contact with the vehicle's brake or clutch pedal, rotate the test dummy's left foot about the lower leg. If there is still pedal interference, rotate the left leg outboard about the hip the minimum distance necessary to avoid the pedal interference. Except as prevented by contact with a vehicle surface, place the left leg so that the upper and lower leg centrelines fall, as close as possible, in a vertical plane. For vehicles with a foot rest that does not elevate the left foot above the level of the right foot, place the left foot on the foot rest so that the upper and lower leg centrelines fall in a vertical plane.

S10.1.2 Passenger position placement.

S10.1.2.1 Vehicles with a flat floor pan/toeboard.

(b) Place the right and left feet on the vehicle's toeboard with the heels resting on the floor pan as close as possible to the intersection point with the toeboard. If the feet cannot be placed flat on the toeboard, set them perpendicular to the lower leg centrelines and place them as far forward as possible with the heels resting on the floor pan.

(c) Place the right and left legs so that the upper and lower leg centrelines fall in vertical longitudinal planes.

S10.1.2.2 Vehicles with wheelhouse projections in passenger compartment.

(b) Place the right and left feet in the well of the floor pan/toeboard and not on the wheelhouse projection. If the feet cannot be placed flat on the toeboard, initially set them perpendicular to the lower leg centrelines and then place them as far forward as possible with the heels resting on the floor pan.

(c) If it is not possible to maintain vertical and longitudinal planes through the upper and lower leg centrelines for each leg, then place the left leg so that its upper and lower centrelines fall as closely as possible in a vertical longitudinal plane and place the right leg so that its upper and lower leg centrelines fall, as closely as possible, in a vertical plane.

Appendix 2

Test Vehicle Data Sheets

BT 225

Test Number	BT 225
Vehicle Name:	Holden VN Commodore Executive
Vehicle Identification Number:	6H8VNK19HML507459
Body Type:	SEDAN
Engine Type:	3.8 litre V-Six Cylinder
Transmission Type:	Automatic, 4 speed.
Drive Type:	Rear Wheel Drive
Laden Mass (kg):	1446
Steering Type:	Power Assisted Rack and Pinion
Air Conditioning:	Yes

Seat

The seat assembly is adjustable for height

Location of Seat Belt Anchorages:

Upper Torso Anchorage to B pillar. Outer Lap anchorage to sill. Inner Lap Anchorage to centre tunnel.

Seat Belt Type:

Driver's:	92030512C	910429
Passenger's:	92030512C	910429

Steering Wheel Description:

Not adjustable for reach or rake.

Glove Compartment Description:

All plastic, single piece moulding.

BT 228

Test Number	BT 228
Vehicle Name:	Mitsibishi Magna TR Executive
Vehicle Identification Number:	6MMTR4D41MA008085
Body Type:	SEDAN
Engine Type:	2.6 litre Four Cylinder
Transmission Type:	Automatic, 4 speed.
Drive Type:	Front Wheel Drive
Laden Mass (kg):	1446
Steering Type:	Power Assisted Rack and Pinion
Air Conditioning:	Yes

Location of Seat Belt Anchorages:

Upper Torso Anchorage on B pillar. Outer Lap Anchorage on sill. Inner Lap Anchorage on seat frame.

Seat Belt Type:

Driver's:	Mitsubishi	AW322996	23/04/91
Passenger's	Mitsubishi	AW322995	08/05/91

Steering Wheel Description:

Adjustable for rake, lever not fully recessed.

Glove Compartment Description:

All plastic, multi-piece construction.

BT 234

Test Number	BT 234
Vehicle Name:	Nissan Pintara Executive
Vehicle Identification Number:	6F4SPRU12K0M13252
Body Type:	SEDAN
Engine Type:	2.0 litre Four Cylinder
Transmission Type:	Automatic, 4 speed.
Drive Type:	Front Wheel Drive
Laden Mass (kg):	1289.5
Steering Type:	Power Assisted Rack and Pinion
Air Conditioning:	Yes

Location of Seat Belt Anchorages:

Upper Torso Anchorage on B pillar. Outer Lap Anchorage on sill. Inner Lap Anchorage on seat frame.

Seat Belt Type:

Driver's:	CCI	186842J800	19/04/91
Passenger's	CCI	186842J800	19/04/91

Steering Wheel Description:

Rake adjustable, lever is recessed.

Glove Compartment Description:

All plastic, multi-piece construction.

BT 235

Test Number	BT 235
Vehicle Name:	Toyota Camry Executive
Vehicle Identification Number:	6T153SV2109136005
Body Type:	SEDAN
Engine Type:	2.0 litre Four Cylinder
Transmission Type:	Automatic, 3 speed.
Drive Type:	Front Wheel Drive
Laden Mass (kg):	1325
Steering Type:	Power Assisted Rack and Pinion
Air Conditioning:	Yes

Location of Seat Belt Anchorages:

Upper Torso Anchorage on B pillar. Outer Lap Anchorage on sill. Inner Lap Anchorage on seat frame.

Seat Belt Type:

Driver's:	CCI	73250YB010	12/04/91
Passenger's	CCI	73250YB010	12/04/91

Steering Wheel Description:

Rake adjustable, lever not recessed.

Glove Compartment Description:

All plastic, multi-piece construction.

BT 236

Test Number:	BT 236
Vehicle Model:	Ford EA Falcon GL
Vehicle Identification Number:	JG23ML40260
Body Type:	SEDAN
Engine Type:	3.9 litre Six Cylinder
Transmission Type:	Automatic, 4 speed.
Drive Type:	Rear Wheel Drive
Test Mass (kg):	1549
Steering Type:	Power Assisted Rack and Pinion
Air Conditioning:	Yes

Location of Seat Belt Anchorages:

Upper Torso Anchorage on B pillar. Outer Lap Anchorage on rocker panel. Inner Lap Anchorage on seat frame.

Seat Belt Type:

Driver's:	SJSFCA	910507
Passenger's:	SJSFCA	910503

Steering Wheel Description:

Adjustable for reach and rake, lever was recessed.

Glove Compartment Description:

All plastic, multi-piece construction.

BT 237

Test Number	BT 237
Vehicle Name:	Ford Laser GL
Vehicle Identification Number:	6FPAAAUK4RMY82358
Body Type:	Hatchback
Engine Type:	1.6 litre Four Cylinder
Transmission Type:	Automatic, 3 speed.
Drive Type:	Front Wheel Drive
Laden Mass (kg):	1115
Steering Type:	Manual Rack and Pinion
Air Conditioning:	Yes

Location of Seat Belt Anchorages:

Upper Torso Anchorage on B pillar and is adjustable. Outer Lap Anchorage on sill. Inner Lap Anchorage on centre seat frame.

Seat Belt Type:

Driver's:	Takata	K524-EH314	04/01/91
Passenger's	Takata	K524-EH314	04/01/91

Steering Wheel Description:

Not adjustable for reach or rake.

Glove Compartment Description:

All plastic, multi-piece construction.

BT 238

Test Number	BT 238
Vehicle Name:	Toyota Corolla GL
Vehicle Identification Number:	6T154AE9209515881
Body Type:	Hatchback
Engine Type:	1.6 litre Four Cylinder
Transmission Type:	Automatic, 3 speed.
Drive Type:	Front Wheel Drive
Laden Mass (kg):	1124
Steering Type:	Power Assisted Rack and Pinion
Air Conditioning:	Yes

Location of Seat Belt Anchorages:

Upper Torso Anchorage on B pillar. Outer Lap Anchorage on sill. Inner Lap Anchorage on centre tunnel.

Seat Belt Type:

Driver's:	CCI	73230YA010	03/04/91
Passenger's	CCI	73230YA010	03/04/91

Steering Wheel Description:

Rake adjustable, lever was fully recessed.

Glove Compartment Description:

All plastic, multi-piece construction.

Appendix 3

Pre and Post-Test Measurements

Appendix 3

Each of the seven vehicles was measured prior to test. The dimensions used various reference points both on the body and underpan area to enable post-test deformation to be determined.

Although a pro-forma was used, variations in the location of key points exist in some measurements because both Front-Wheel-Drive (FWD) and Rear-Wheel-Drive (RWD) vehicles were tested. These variations are indicated where appropriate.

Items which were recorded included the following:

- Passenger Compartment external dimensions. Six key measurements A through F where recorded (same for both FWD and RWD vehicles). These include door openings at A, B and C pillars, distance between A and B, and A and C pillars, and A pillar length.
- Underpan Mechanicals. Different dimensions were recorded according to whether the vehicle was FWD or RWD. Measurements were made from targets towards the rear of the vehicle midway point on the underside of the floorpan. Common measurements included Front Edge of Floorpan, Front Bumper, Steering Rack and Pinion Centreline.
- Location of front Seat Belt Anchorage Points from a target towards the rear.
  - A — the horizontal distance from the target to the Upper Torso Anchorage (UTA)
  - B — the horizontal distance to the Outer Lap Anchorage OLA
  - C — the horizontal distance to the Inner Lap Anchorage ILA
  - D or D+E the vertical distance between the UTA and the OLA.
- Seat Belt Loop Length for Lap and Sash Belt.
- Dummy Positioning within the vehicle for Driver and Passenger as set out in Section 11, FMVSS 208.

The pre and post-test measurements for each vehicle are given in the following tables.

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

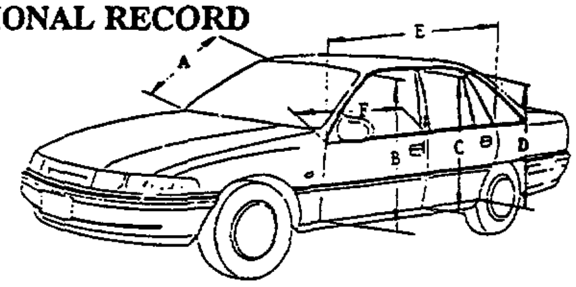
ENGINEERING REPORT

DIMENSIONAL RECORD

Barrier Test No.: BT 225
Date: September 12, 1991
Dimensions in mm

Operator:..........

Engineer:..........



PASSENGER COMPARTMENT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	...710....	...710....	....0.....	...724....	...722....	....2.....
B	..1063....	..1088....	...-25....	..1077....	..1104....	...-27....
C	..1109....	..1108....	....1.....	..1112....	..1114....	....-2....
D	..1087....	..1092....	...-5.....	..1094....	..1103....	....-9....
E	..1990....	..1967....	....23....	..1992....	..1964....	....28....
F	..1014....	..998.....	....16....	..1010....	...993....	....17....

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
Overall Length Front to Rear Datum.	4500	3810	690	4500	3880	690
"A" Pillar to Strut Tower.	644	613	31	640	624	16
Instrument Panel to Parcel Shelf Targets	1931	1906	25	1930	1902	28

	BEFORE	AFTER	RESIDUAL
Instrument Panel to Parcel Shelf C/L	1946	11916	30
Steering Wheel Target to Reference Target	1787	1791	-4
Between Strut Towers	1239	1152	87

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

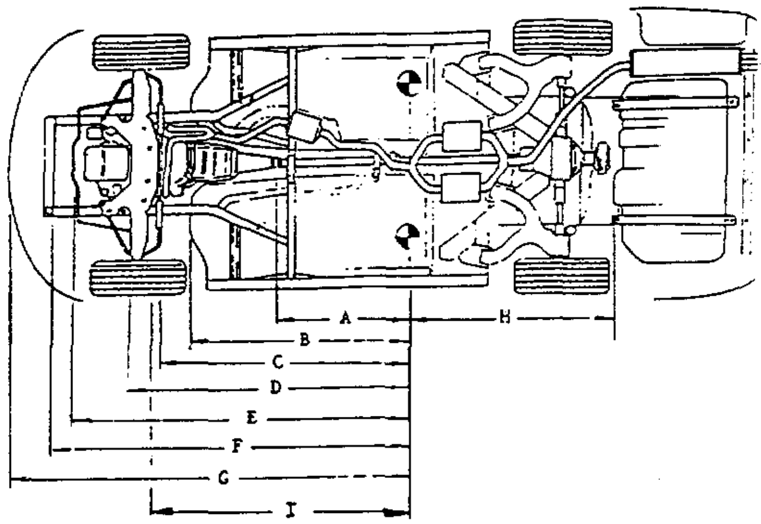
ENGINEERING REPORT

DIMENSIONAL RECORD / REAR WHEEL DRIVE

Barrier Test No.: BT 225
Date: September 12, 1991
Dimensions in mm

Operator:........

Engineer:........



	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A Centre First Universal Joint	881	797	84	---	---	---
B Front Edge of Floorpan	1544	1462	82	1542	1465	77
C Front Face Transmission	1719	1607	112	---	---	---
D Front Face Cross Member	1958	1827	131	1952	1831	121
E Engine Front Face	2259	2180	79	---	---	---
F Radiator Lower Rear Edge	2512	2138	374	2510	2157	353
G Front Bumper	2868	2179	689	2862	2194	668
H Rear Edge of Fuel Tank	1625	1600	25	1610	1589	21
I Steering R+P Centerline	1792	1678	114	---	---	---

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GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

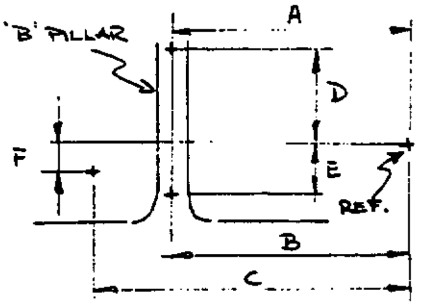
ENGINEERING REPORT

DIMENSIONAL RECORD

Vehicle :
Barrier Test No.: BT225
Date:
Dimensions in mm

Operator:..

Engineer:..



SEAT BELT ANCHORAGE POINT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	1075	1107	-32	1076	1098	-22
B	735	733	2	735	729	6
C	915	894	21	915	893	22
D	832	821	11	832	827	5
E						
F						

SEAT BELT LOOP LENGTH

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
L1	850	980	-130	820	920	-100
L2	830	845	-15	820	830	-10

L1: LAP BELT
L2: SASH BELT

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

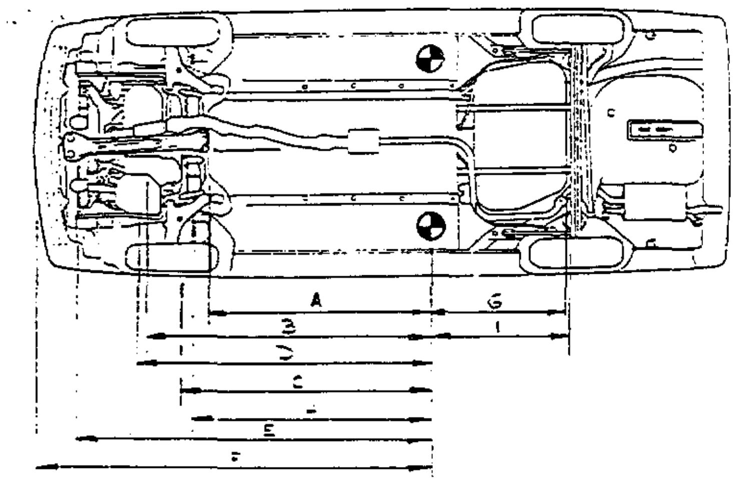
ENGINEERING REPORT

DIMENSIONAL RECORD / FRONT WHEEL DRIVE

Barrier Test No.: BT 228
Date: 19th Sep. 1991
Dimensions in mm

Operator: ....

Engineer: ....

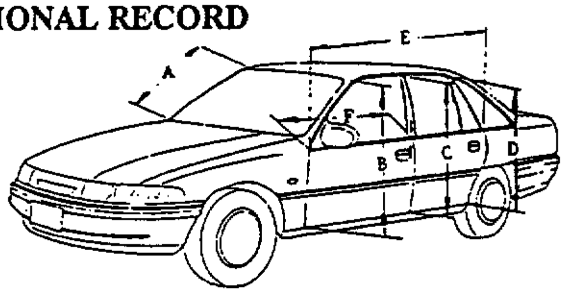


	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A Front Edge of Floorpan	1447	1340	107	1449	1365	84
B Centerline of Transmission	2050	1880	170			
C Front Face Cross Member	1787	1642	145	1787	1686	101
D Centreline of Engine				2055	1877	178
E Radiator Lower Rear Edge	2552	2245	307	2547	2230	317
F Front Bumper	2775	2419	356	2778	2434	344
G Rear Edge of Fuel Tank	808	802	6	804	803	1
H Steering R+P Centerline	1685	1546	139	1684	1562	122

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

ENGINEERING REPORT

DIMENSIONAL RECORD



Barrier Test No.: BT 228
Date: 19th Sep. 1991
Dimensions in mm

Operator:.........

Engineer:.........

PASSENGER COMPARTMENT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	714	714	0	718	712	6
B	1086	1088	-2	1090	1088	2
C	1142	1141	1	1142	1143	-1
D	1123	1124	-1	1119	1123	-4
E	1975	1967	8	1990	1983	7
F	1003	997	6	1001	994	7

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
Overall Length Front to Rear Datum.	4500	3980	520	4500	3980	520
"A" Pillar to Strut Tower.	604	545	59	600	541	59
Instrument Panel to Parcel Shelf Targets	1902	1886	16	1910	1903	7

	BEFORE	AFTER	RESIDUAL
Instrument Panel to Parcel Shelf C/L	1847	1829	18
Steering Wheel Target to Reference Target	1788	1764	24
Between Strut Towers	1333	1243	90

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

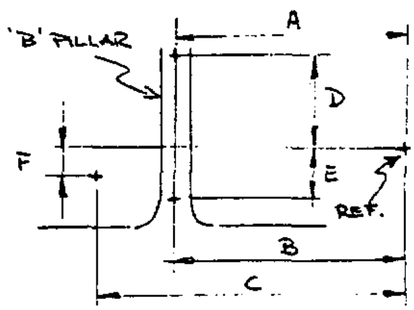
ENGINEERING REPORT

DIMENSIONAL RECORD

Barrier Test No.: BT 228
Date: 19th Sep. 1991
Dimensions in mm

Operator: ....

Engineer: ....



SEAT BELT ANCHORAGE POINT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	1076	1097	-21	1084	1095	-11
B	830	909	-79	911	910	1
C	1030	1031	-1	1030	1033	-3
D	830	815	15	830	819	11
E						
F						

SEAT BELT LOOP LENGTH

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
L1	860	960	-100	870	900	-30
L2	825	832	-7	813	816	-3

L1: LAP BELT
L2: SASH BELT

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

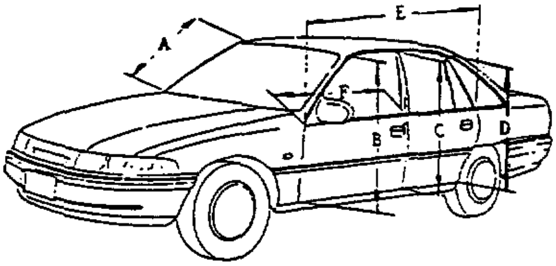
ENGINEERING REPORT

DIMENSIONAL RECORD

Barrier Test No.: BT 234
Date: 19th Sep. 1991
Dimensions in mm

Operator:...........

Engineer:...........



PASSENGER COMPARTMENT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	771	770	1	772	771	1
B	1037	1045	-8	1040	1057	-17
C	1068	1069	-1	1074	1077	-3
D	1047	1050	-3	1043	1045	-2
E	2016	2000	16	2016	2000	16
F	991	980	11	995	983	12

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
Overall Length Front to Rear Datum.	4000	3430	570	4000	3460	540
"A" Pillar to Strut Tower.	653	628	25	660	634	26
Instrument Panel to Parcel Shelf Targets	1931	1908	23	1935	1922	13

	BEFORE	AFTER	RESIDUAL
Instrument Panel to Parcel Shelf C/L	1954	1932	22
Steering Wheel Target to Reference Target	1766	1746	20
Between Strut Towers	1180	1042	138

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

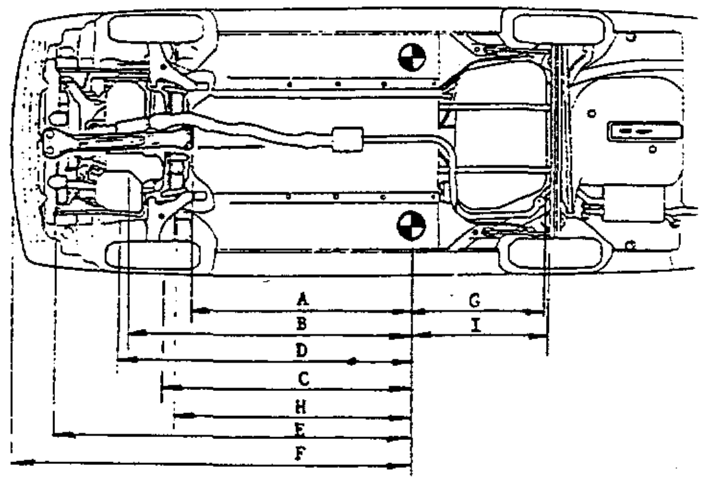
ENGINEERING REPORT

DIMENSIONAL RECORD / FRONT WHEEL DRIVE

Barrier Test No.: BT 234
Date: 19th Sep. 1991
Dimensions in mm

Operator:........

Engineer:........



	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A Front Edge of Floorpan	1171	1096	75	1090	1031	59
B Centerline of Transmission	1842	1723	119	--	--	--
C Front Face Cross Member	1508	1422	86	1423	1350	73
D Centreline of Engine	--	--	--	1756	1583	173
E Radiator Lower Rear Edge	2280	1925	355	2197	1841	356
F Front Bumper	2545	2020	525	2465	1932	533
G Rear Edge of Fuel Tank	890	886	4	960	956	4
H Steering R+P Centerline	1453	1348	105	1370	1277	93
I Front Edge of Rear Axle	1034	1036	-2	1095	1092	3

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

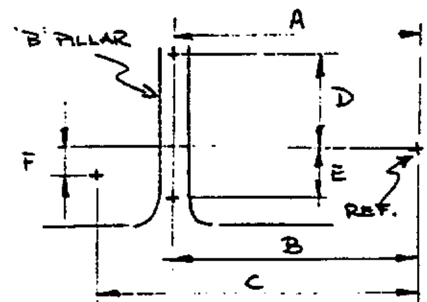
ENGINEERING REPORT

DIMENSIONAL RECORD

Barrier Test No.: BT 234
Date: 19th Sep. 1991
Dimensions in mm

Operator: ....

Engineer: ....



SEAT BELT ANCHORAGE POINT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	1073	1076	-3	1076	1081	-5
B	769	775	-6	769	770	-1
C	288	288	0	288	289	-1
D+E	805	796	9	805	798	7

SEAT BELT LOOP LENGTH

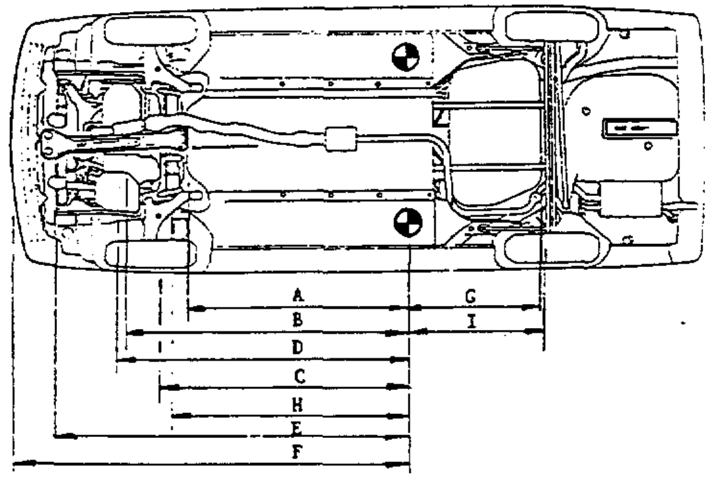
	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
L1	825	895	-70	800	850	-50
L2	794	802	-8	795	800	-5

L1: LAP BELT
L2: SASH BELT

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

ENGINEERING REPORT

DIMENSIONAL RECORD / FRONT WHEEL DRIVE



Barrier Test No.: BT 235
Date: 2nd Oct. 1991
Dimensions in mm

Operator:

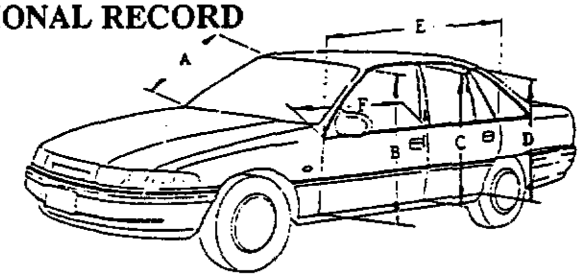
Engineer:

DIMENSION (mm)	LEFT HAND SIDE BEFORE	LEFT HAND SIDE AFTER	LEFT HAND SIDE RESIDUAL	RIGHT HAND SIDE BEFORE	RIGHT HAND SIDE AFTER	RIGHT HAND SIDE RESIDUAL
A Front Edge of Floorpan	1387	1361	26	1387	1353	34
B Centerline of Transmission	1880	1725	155	--	--	--
C Front Face Cross Member	1695	1555	140	1734	1625	109
D Centreline of Engine	--	--	--	2015	1861	154
E Radiator Lower Rear Edge	2425	2126	299	2428	2127	301
F Front Bumper	2664	2165	499	2661	2177	484
G Rear Edge of Fuel Tank	672	663	9	671	655	16
H Steering R+P Centerline	--	--	--	1641	1540	101
I Front Edge of Rear Axle	729	733	-4	728	730	-2

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

ENGINEERING REPORT

DIMENSIONAL RECORD



Barrier Test No.: BT 235
Date: 2nd Oct. 1991
Dimensions in mm

Operator:

Engineer:

PASSENGER COMPARTMENT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	702	702	0	690	690	0
B	1077	1076	1	1072	1069	3
C	1109	1109	0	1108	1108	0
D	1081	1081	0	1070	1071	-1
E	1883	1880	3	1883	1879	4
F	999	998	1	1005	1002	3

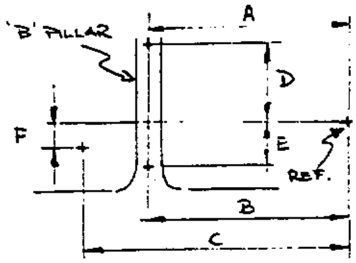
	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
Overall Length Front to Rear Datum.	4000	3510	490	4000	3530	470
"A" Pillar to Strut Tower.	663	613	50	658	611	47
Instrument Panel to Parcel Shelf Targets	1890	1885	5	1893	1889	4

	BEFORE	AFTER	RESIDUAL
Instrument Panel to Parcel Shelf C/L	1886	1865	21
Steering Wheel Target to Reference Target	1752	1755	-3
Between Strut Towers	1155	1045	110

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

ENGINEERING REPORT

DIMENSIONAL RECORD



Barrier Test No.: BT 235
Date: 2nd Oct. 1991
Dimensions in mm

Operator:..............

Engineer:..............

SEAT BELT ANCHORAGE POINT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	932	939	-7	932	938	-6
B	400	400	0	410	409	1
C	499	530	31	497	568	-71
D+E	811	808	3	815	809	6

SEAT BELT LOOP LENGTH

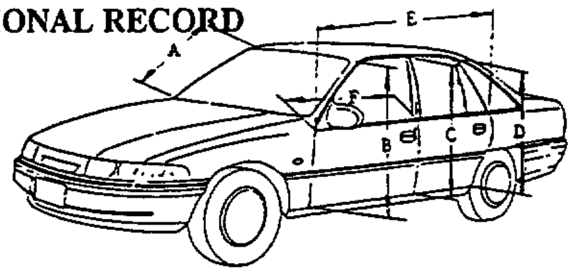
	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
L1	886	899	-13	840	884	-44
L2	854	910	-56	865	845	20

L1: LAP BELT
L2: SASH BELT

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

ENGINEERING REPORT

DIMENSIONAL RECORD



Barrier Test No.: BT 236
Date: 3rd Oct. 1991
Dimensions in mm

Operator:..........

Engineer:..........

PASSENGER COMPARTMENT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	730	730	0	720	722	-2
B	1077	1096	-19	1084	1103	-19
C	1121	1125	-4	1120	1124	-4
D	1112	1130	-18	1098	1113	-15
E	2011	1986	25	1997	1977	20
F	1014	999	15	995	979	16

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
Overall Length Front to Rear Datum.	4500	4010	490	4500	4025	475
"A" Pillar to Strut Tower.	732	730	2	749	739	10
Instrument Panel to Parcel Shelf Targets	1958	1932	26	1928	1907	21

	BEFORE	AFTER	RESIDUAL
Instrument Panel to Parcel Shelf C/L	1935	1905	30
Steering Wheel Target to Reference Target	1789	1810	-21
Between Strut Towers	1187	1130	57

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

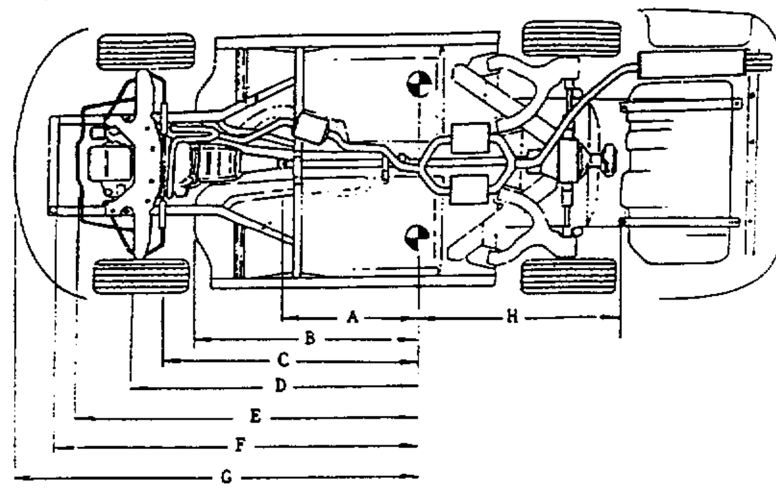
ENGINEERING REPORT

DIMENSIONAL RECORD / REAR WHEEL DRIVE

Barrier Test No.: BT 236
Date: 3rd Oct. 1991
Dimensions in mm

Operator: ......

Engineer: ......



	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A Centre First Universal Joint	1205	1172	33	--	--	--
B Front Edge of Floorpan	1719	1710	9	1719	1720	-1
C Front Face Transmission	2064	1986	78	--	--	--
D Front Face Cross Member	2464	2412	52	2462	2409	53
E Engine Front Face	2680	2598	82	--	--	--
F Radiator Lower Rear Edge	2880	2652	228	2881	2665	216
G Front Bumper	3218	2798	420	3218	2810	408
H Rear Edge of Fuel Tank	1383	1333	50	--	--	--
I Steering R+P Centerline	2269	2197	72	2270	2203	67

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GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

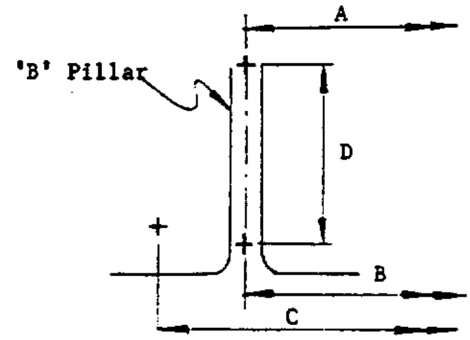
ENGINEERING REPORT

DIMENSIONAL RECORD

Barrier Test No.: BT 236
Date: 3rd Oct. 1991
Dimensions in mm

Operator:........

Engineer:........



SEAT BELT ANCHORAGE POINT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	938	965	-27	940	968	-28
B	343	346	-3	341	348	-7
C	530	573	-43	534	593	-59
D	820	808	12	819	802	17

SEAT BELT LOOP LENGTH

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
L1	873	945	-72	867	900	-33
L2	883	920	-37	861	900	-39

L1: LAP BELT
L2: SASH BELT

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

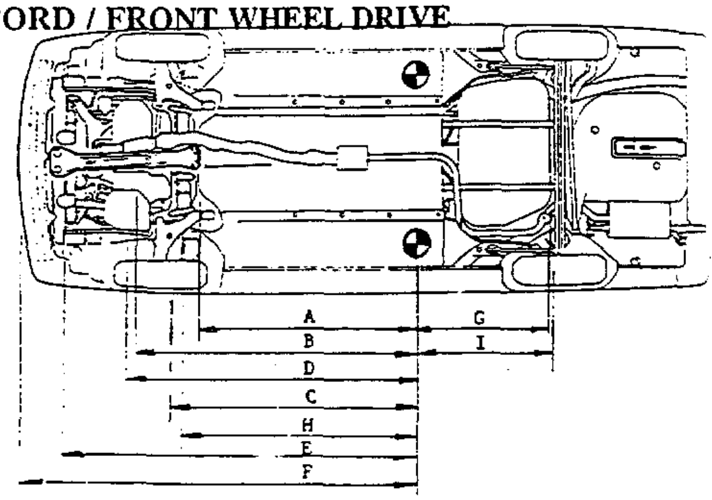
ENGINEERING REPORT

DIMENSIONAL RECORD / FRONT WHEEL DRIVE

Barrier Test No.: BT 237
Date: 10th Oct. 1991
Dimensions in mm

Operator: ....

Engineer: ....

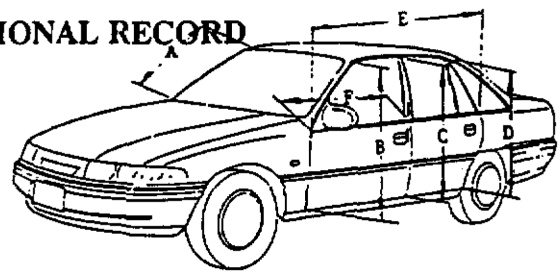


	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A Front Edge of Floorpan	1200	1070	130	1211	1110	101
B Centerline of Transmission	1818	1625	193	--	--	--
C Front Face Cross Member	1643	1490	153	1643	1515	128
D Centreline of Engine	--	--	--	1802	1559	243
E Radiator Lower Rear Edge	2192	1849	343	2192	1809	383
F Front Bumper	2415	1970	445	2418	1895	523
G Rear Edge of Fuel Tank	716	695	21	738	725	13
H Steering R+P Centerline	--	--	--	1440	1297	143
I Front Edge of Rear Axle	846	849	-3	842	851	-9

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

ENGINEERING REPORT

DIMENSIONAL RECORD



Barrier Test No.: BT 237
Date: 10th Oct. 1991
Dimensions in mm

Operator:.........

Engineer:.........

PASSENGER COMPARTMENT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	659	658	1	650	648	2
B	1017	1022	-5	1020	1025	-5
C	1072	1069	3	1073	1068	5
D	1063	1061	2	1064	1061	3
E	1964	1956	8	1962	1956	6
F	980	971	9	960	954	6

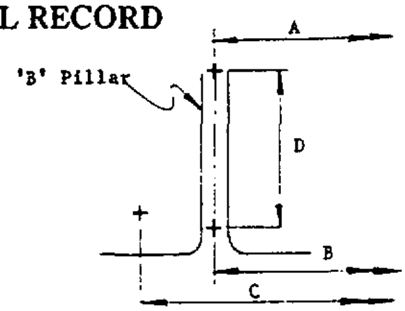
	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
Overall Length Front to Rear Datum.	3500	3115	385	3500	2991	509
"A" Pillar to Strut Tower.	640	578	62	649	568	81
Instrument Panel to Parcel Shelf Targets	1741	1732	9	1735	1730	5

	BEFORE	AFTER	RESIDUAL
Instrument Panel to Parcel Shelf C/L	1638	1634	4
Steering Wheel Target to Reference Target	1665	1680	-15
Between Strut Towers	1098	1021	77

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

ENGINEERING REPORT

DIMENSIONAL RECORD



Barrier Test No.: BT 237
Date: 10th Oct. 1991
Dimensions in mm

Operator:........

Engineer:........

SEAT BELT ANCHORAGE POINT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	1010	1011	-1	1011	1011	0
B	312	314	-2	312	314	-2
C	492	560	-68	482	482	0
D	771	771	0	769	770	-1

SEAT BELT LOOP LENGTH

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
L1	872	835	37	860	870	-10
L2	840	880	-40	825	835	-10

L1: LAP BELT
L2: SASH BELT

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

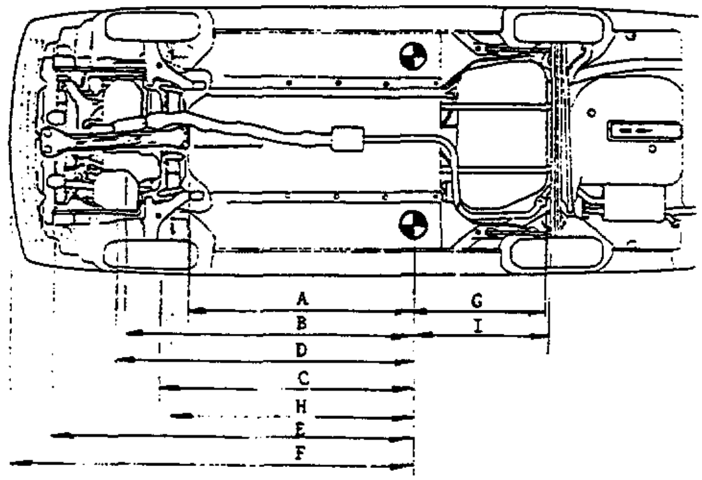
ENGINEERING REPORT

DIMENSIONAL RECORD / FRONT WHEEL DRIVE

Barrier Test No.: BT 238
Date: 11th Oct. 1991
Dimensions in mm

Operator:.............

Engineer:..........



	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A Front Edge of Floorpan	1120	1098	22	1120	1078	42
B Centerline of Transmission	1869	1741	128	--	--	--
C Front Face Cross Member	1571	1460	111	1625	1528	97
D Centreline of Engine	--	--	--	1850	1678	172
E Radiator Lower Rear Edge	2287	1945	342	2297	1959	338
F Front Bumper	2465	1985	480	2466	2000	466
G Rear Edge of Fuel Tank	673	661	12	669	659	10
H Steering R+P Centerline	--	--	--	1514	1415	99
I Front Edge of Rear Axle	791	796	-5	788	791	-3

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

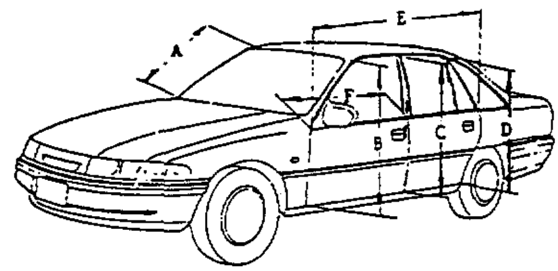
ENGINEERING REPORT

DIMENSIONAL RECORD

Barrier Test No.: BT 238
Date: 11th Oct. 1991
Dimensions in mm

Operator:..........

Engineer:..........



PASSENGER COMPARTMENT DEFORMATION

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	737	737	0	740	738	2
B	1019	1021	-2	1016	1019	-3
C	1061	1061	0	1061	1061	0
D	1048	1047	1	1050	1049	1
E	1898	1893	5	1900	1896	4
F	993	986	7	991	986	5

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIMENSION (mm)	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
Overall Length Front to Rear Datum.	3500	3013	487	3500	2996	504
"A" Pillar to Strut Tower.	582	520	62	582	538	44
Instrument Panel to Parcel Shelf Targets	1715	1709	6	1708	1665	43

	BEFORE	AFTER	RESIDUAL
Instrument Panel to Parcel Shelf C/L	1661	1653	8
Steering Wheel Target to Reference Target	1620	1614	6
Between Strut Towers	1169	1058	111

GENERAL MOTORS HOLDEN'S AUTOMOTIVE LIMITED
EXPERIMENTAL ENGINEERING - PROVING GROUND

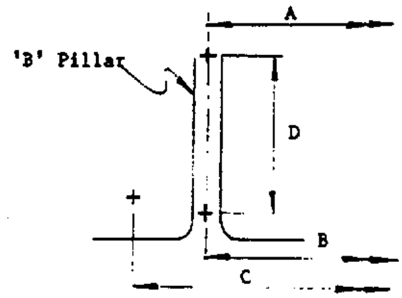
ENGINEERING REPORT

DIMENSIONAL RECORD

Barrier Test No.: BT 238
Date: 11th Oct. 1991
Dimensions in mm

Operator:........

Engineer:........



SEAT BELT ANCHORAGE POINT DEFORMATION

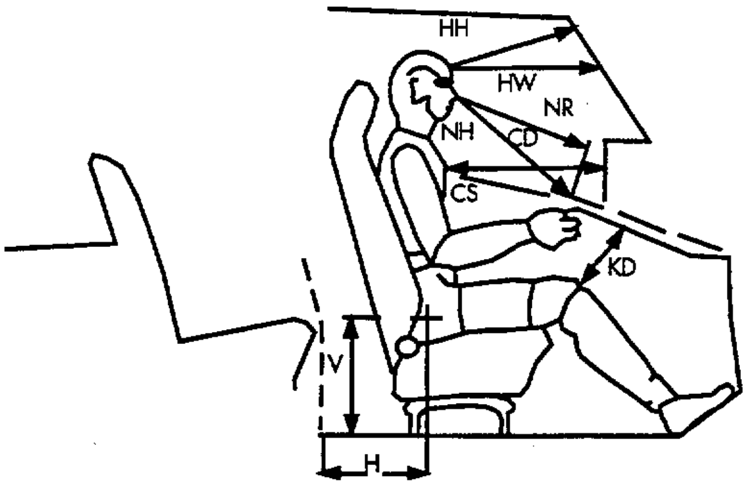
	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
A	1042	1044	-2	1042	1044	-2
B	303	306	-3	299	302	-3
C	244	246	-2	246	246	0
D	815	815	0	818	818	0

SEAT BELT LOOP LENGTH

	LEFT HAND SIDE			RIGHT HAND SIDE		
DIM	BEFORE	AFTER	RESIDUAL	BEFORE	AFTER	RESIDUAL
L1	878	900	-22	878	895	-17
L2	812	830	-18	810	840	-30

L1: LAP BELT
L2: SASH BELT

DUMMY POSITIONING IN VEHICLE



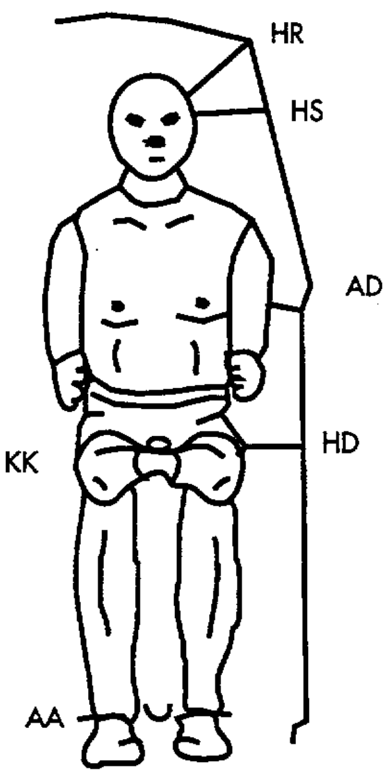
	Driver	Passenger
HH	314	321
HW	422	445
CD	543	620
CS	313	N/A
KD	L - 172	L - 168
KD	R - 175	R - 167
Torso Angle	23.5 °	24.5°
Seat Back Angle	25°	25 °
NR -	400	635
NH	466	-

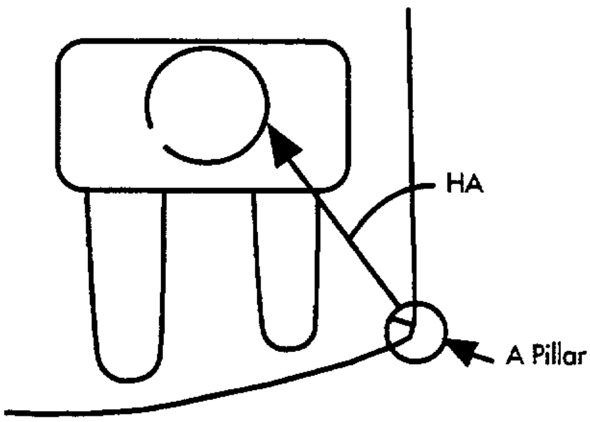
NR: Tip of Dummy's nose to top rear surface of Steering Wheel.
NH: Tip of Dummy's nose to centre of Steering Column Hub.

EA = Head Target to A pillar
HH = Head to Windshield Header
HW = Head to Windshield
CD = Chest to Dash
CS = Chest to Steering Wheel
KD = Knees to Dash
HR = Head to Side Roof
HS = Head to Side Window
AD = Arm to Door
HD = Hip to Door
KK = Knee to Knee

Torso and seat back angles are relative to vertical.

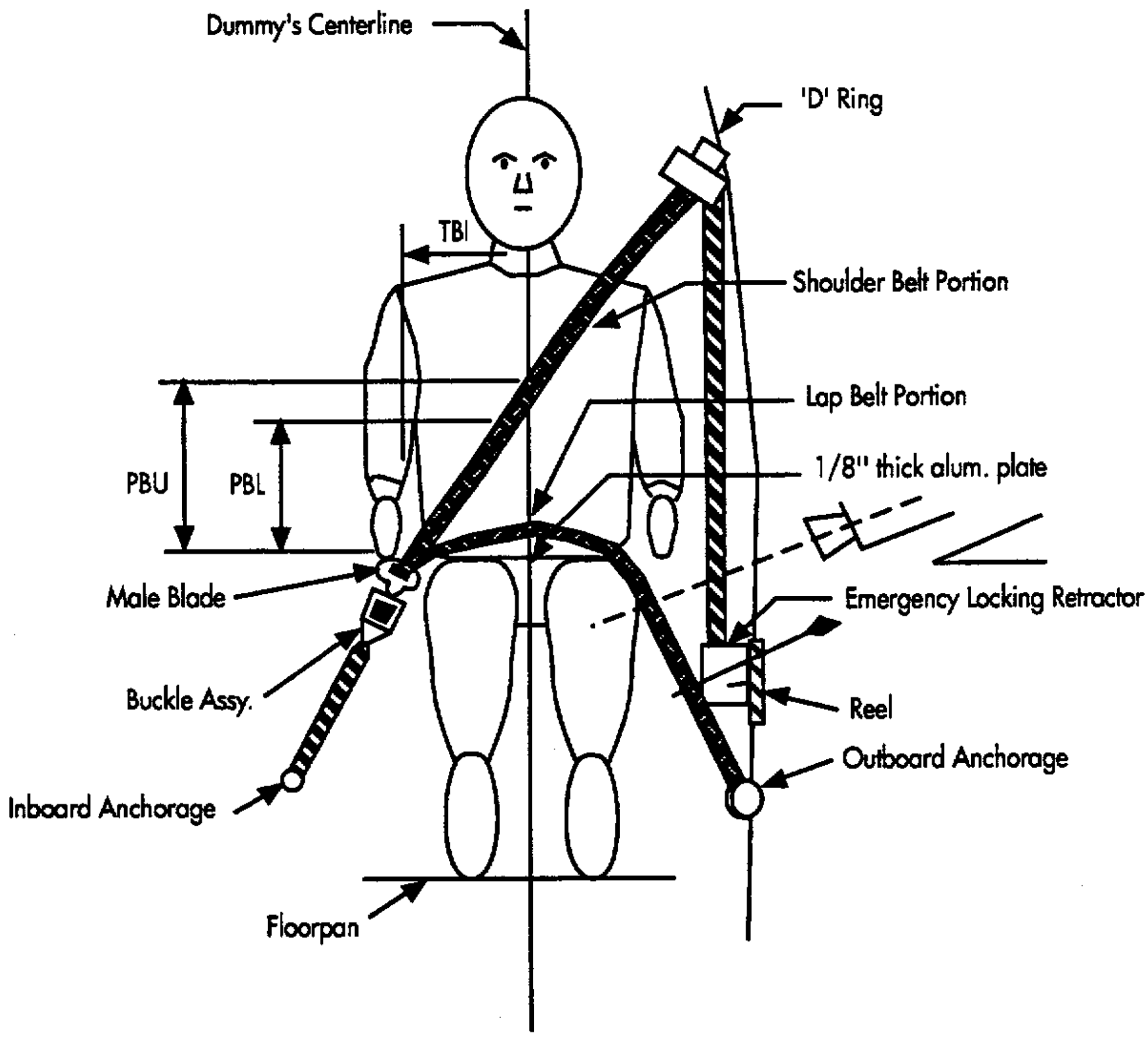
H: 'H' POINT TO REFERENCE TARGET/HORIZONTAL
V: 'H' POINT TO REFERENCE TARGET/VERTICAL
AA: ANKLE TO ANKLE INNER EDGES





	Driver	Passenger
HR	177	188
HS	N/A	N/A
AD	133	129
HD	202	237
KK	190	190
AA	184	130
EA	303	344

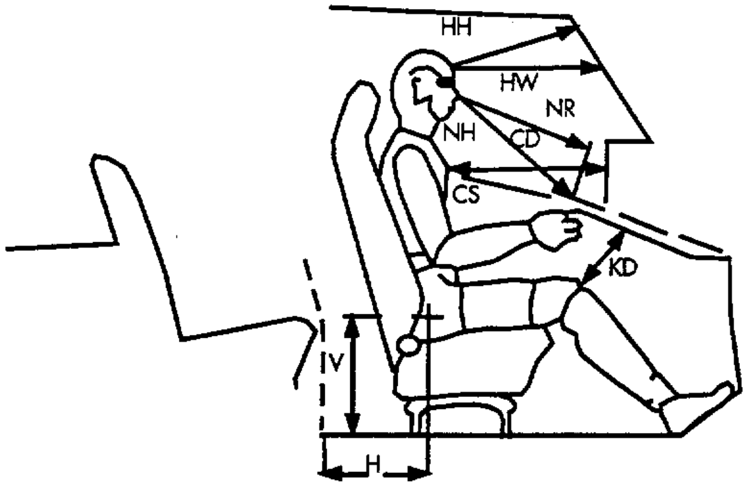
SEAT BELT POSITIONING DATA



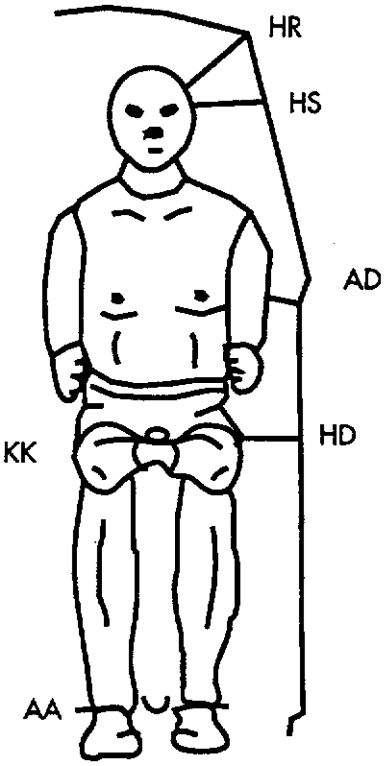
FRONT VIEW OF DRIVER DUMMY

	Driver Dummy	Passenger Dummy
PSU: Top surface of alum. plate to belt upper edge	310	291
PSL: Top surface of alum. plate to belt lower edge	235	215
TBI: Vertical centerline of 50 percentile dummy to intersection of upper torso belt to lap belt	223	222
KC: Dummy knee to camera lens	340	340
X: On board camera angle	0°	0°

DUMMY POSITIONING IN VEHICLE



Driver		Passenger
HH	261	258
HW	404	401
CD	525	542
CS	350	N/A
KD	L - 144	L - 155
KD	R - 140	R - 160
Torso Angle	25°	25°
Seat Back Angle	25°	25°
NR -	405	
NH	438	

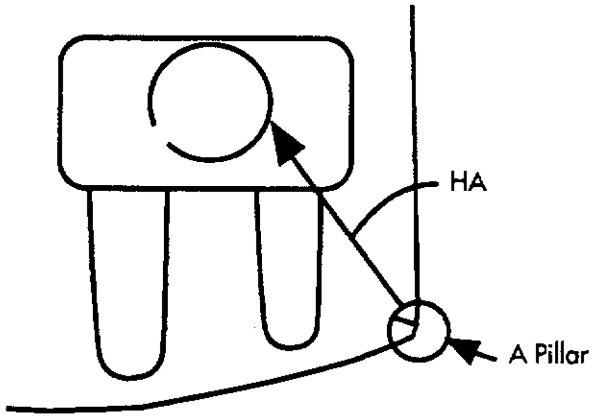


NR: Tip of Dummy's nose to top rear surface of Steering Wheel.
NH: Tip of Dummy's nose to centre of Steering Column Hub.

EA = Head Target to A pillar
HH = Head to Windshield Header
HW = Head to Windshield
CD = Chest to Dash
CS = Chest to Steering Wheel
KD = Knees to Dash
HR = Head to Side Roof
HS = Head to Side Window
AD = Arm to Door
HD = Hip to Door
KK = Knee to Knee

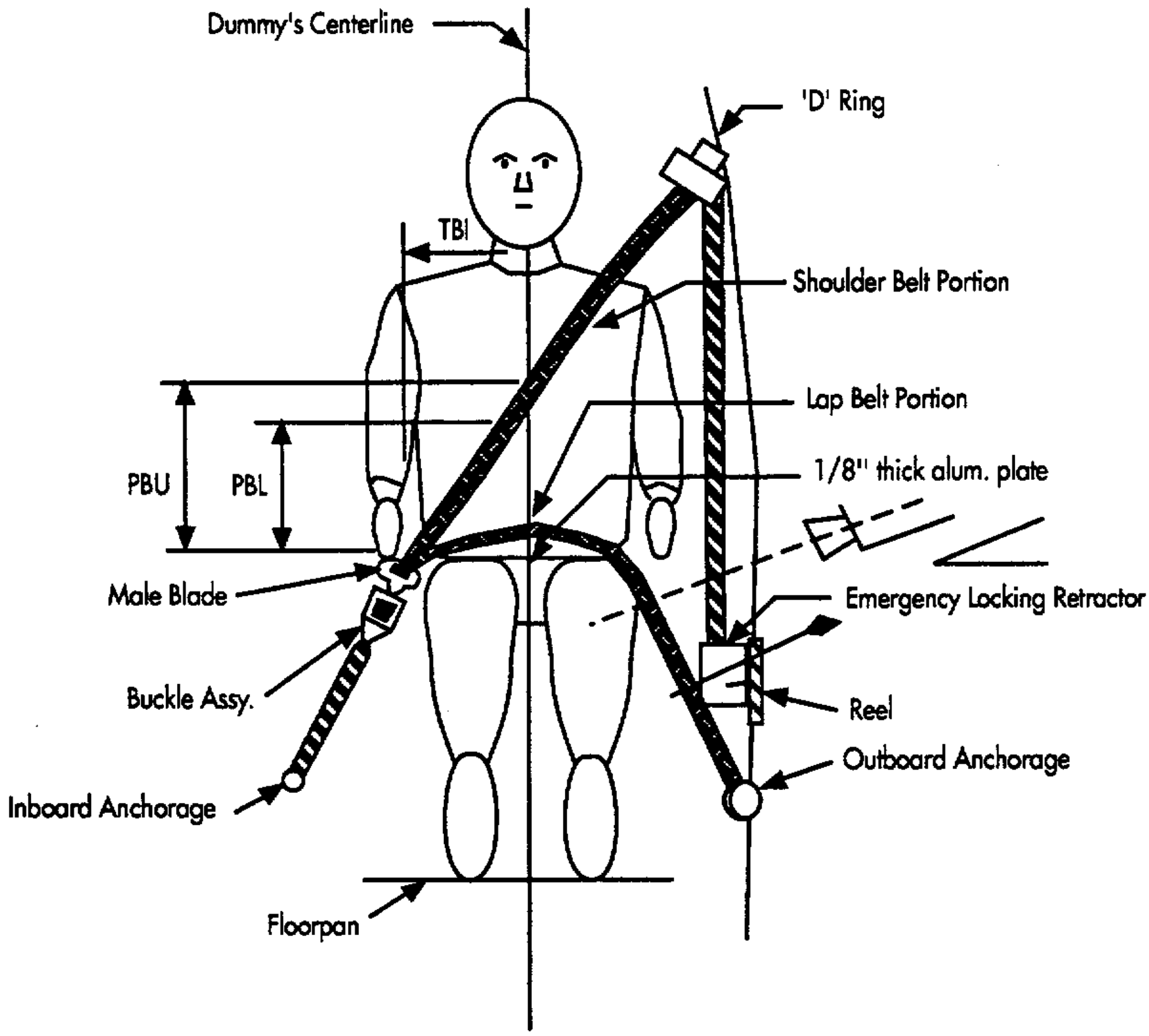
Torso and seat back angles are relative to vertical.

H: 'H' POINT TO REFERENCE TARGET/HORIZONTAL
V: 'H' POINT TO REFERENCE TARGET/VERTICAL
AA: ANKLE TO ANKLE INNER EDGES



	Driver	Passenger
HR	143	135
HS	N/A	N/A
AD	130	95
HD	200	190
KK	270	270
AA	180	150
EA	269	255

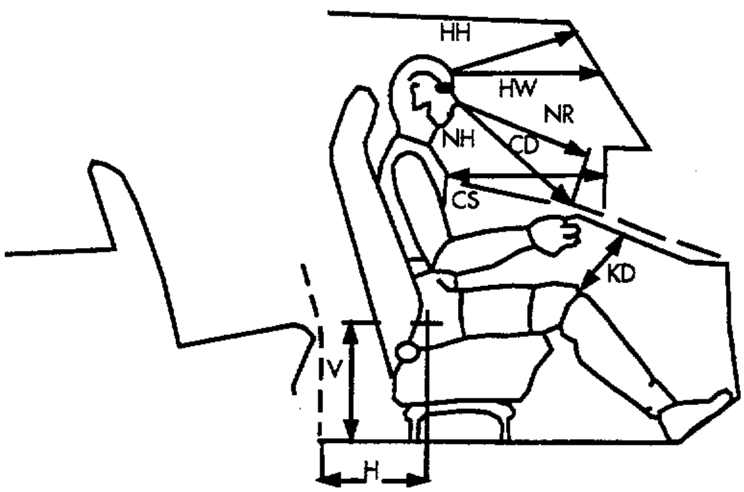
SEAT BELT POSITIONING DATA



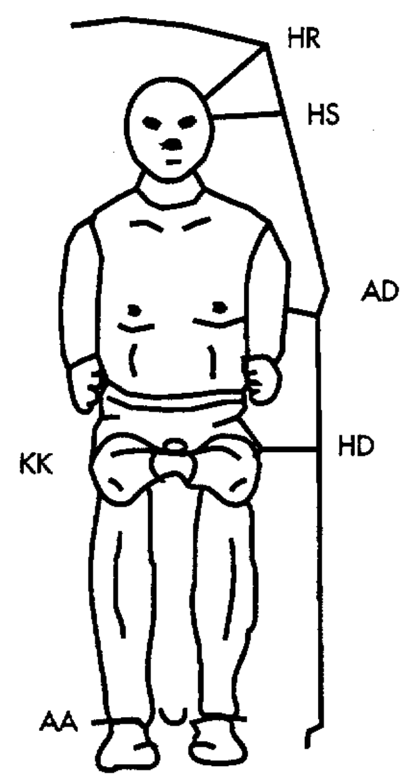
FRONT VIEW OF DRIVER DUMMY

	Driver Dummy	Passenger Dummy
PSU: Top surface of alum. plate to belt upper edge	305	320
PSL: Top surface of alum. plate to belt lower edge	226	243
TBI: Vertical centerline of 50 percentile dummy to intersection of upper torso belt to lap belt	208	215
KC: Dummy knee to camera lens	330	350
X: On board camera angle	13°	13°

DUMMY POSITIONING IN VEHICLE



	Driver	Passenger
HH	279	256
HW	444	381
CD	628	505
CS	318	N/A
KD	L - 140	L - 157
KD	R - 131	R - 160
Torso Angle	25°	24.5°
Seat Back Angle	25°	25°
NR -	411	N/A
NH	425	N/A
V	152	158
H	160	177

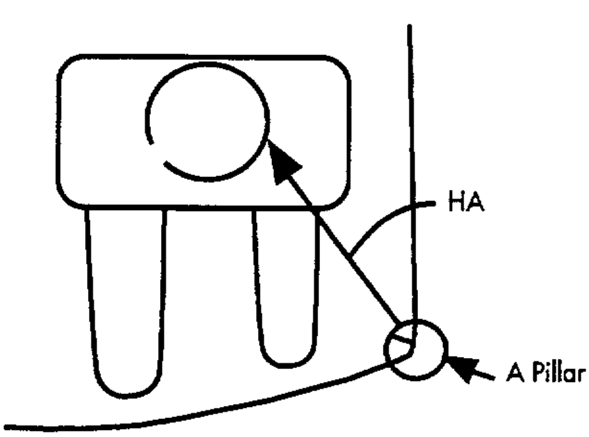


NR: Tip of Dummy's nose to top rear surface of Steering Wheel.
NH: Tip of Dummy's nose to centre of Steering Column Hub.

EA = Head Target to A pillar
HH = Head to Windshield Header
HW = Head to Windshield
CD = Chest to Dash
CS = Chest to Steering Wheel
KD = Knees to Dash
HR = Head to Side Roof
HS = Head to Side Window
AD = Arm to Door
HD = Hip to Door
KK = Knee to Knee

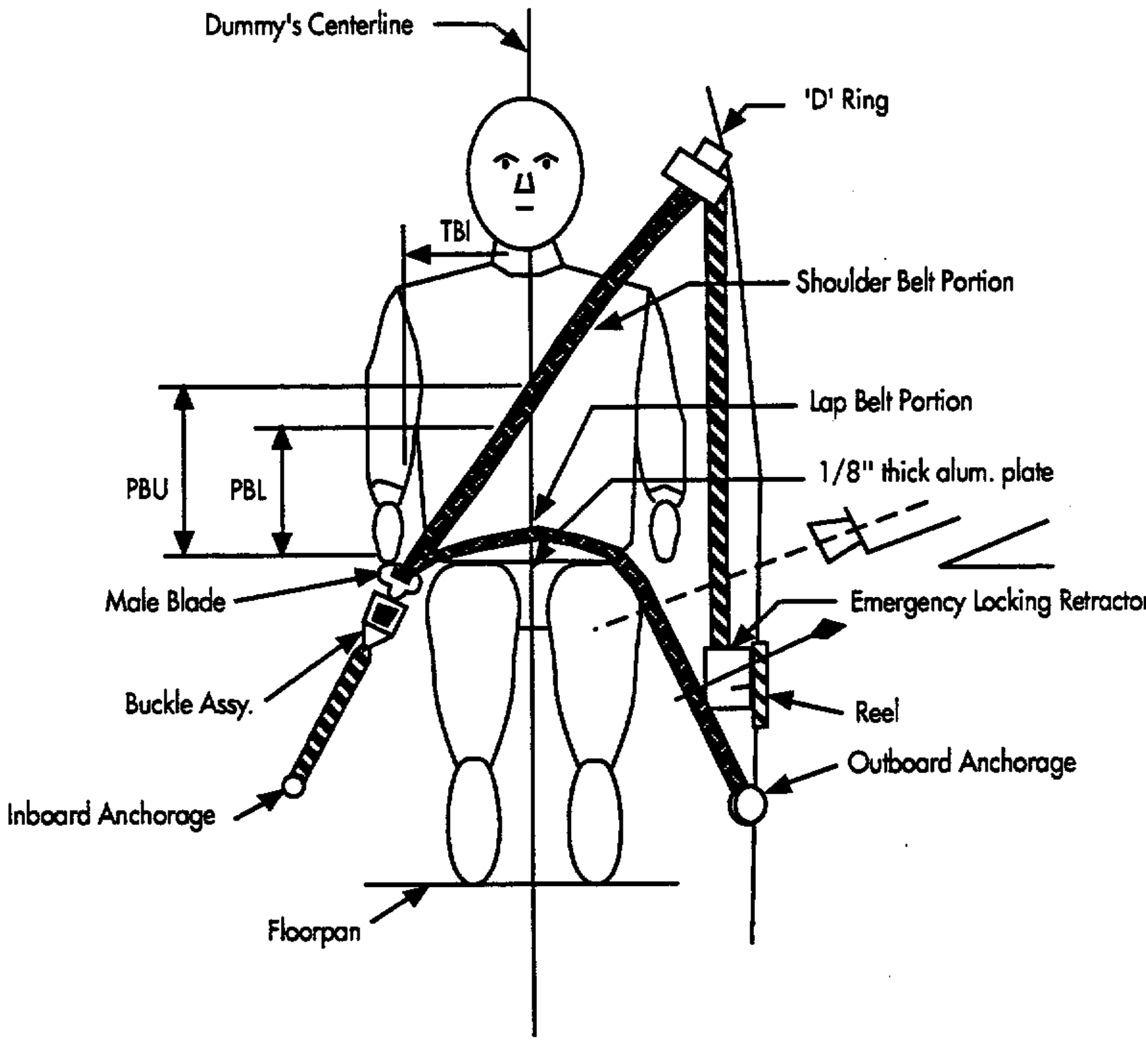
Torso and seat back angles are relative to vertical.

H: 'H' POINT TO REFERENCE TARGET/HORIZONTAL
V: 'H' POINT TO REFERENCE TARGET/VERTICAL
AA: ANKLE TO ANKLE INNER EDGES



	Driver	Passenger
HR	155	143
HS	N/A	N/A
AD	120	107
HD	190	196
KK	270	270
AA	150	155
EA	287	269

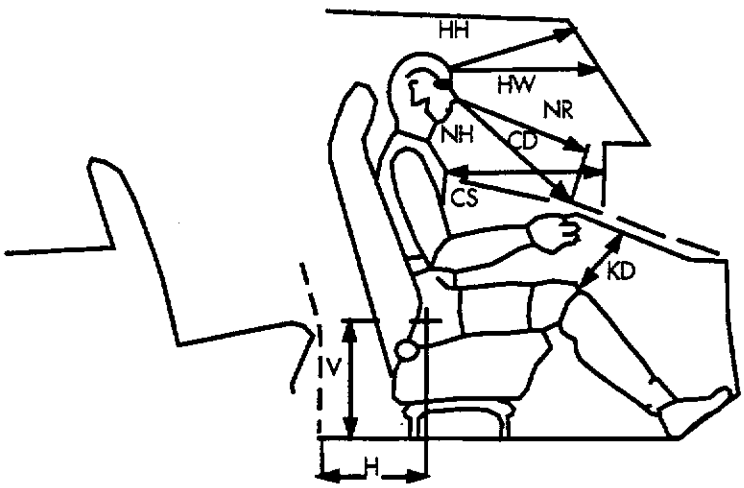
SEAT BELT POSITIONING DATA



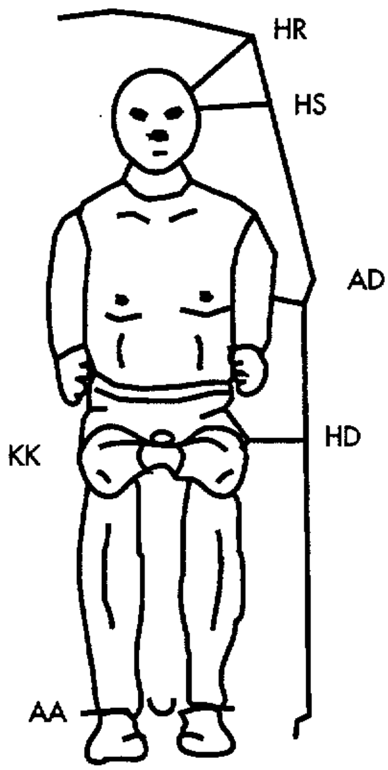
FRONT VIEW OF DRIVER DUMMY

	Driver Dummy	Passenger Dummy
PSU: Top surface of alum. plate to belt upper edge	330	335
PSL: Top surface of alum. plate to belt lower edge	255	253
TBI: Vertical centerline of 50 percentile dummy to intersection of upper torso belt to lap belt	213	215
KC: Dummy knee to camera lens	340	340
X: On board camera angle	15°	15°
SC: Sash belt/chest contact to sash point	340	340

DUMMY POSITIONING IN VEHICLE



	Driver	Passenger
HH	246	273
HW	441	428
CD	534	600
CS	321	N/A
KD	L - 165	L - 159
KD	R - 155	R - 163
Torso Angle	24.5 °	23.5 °
Seat Back Angle	25°	25°
NR -	387	N/A
NH	420	N/A
V	164	172
H	163	168

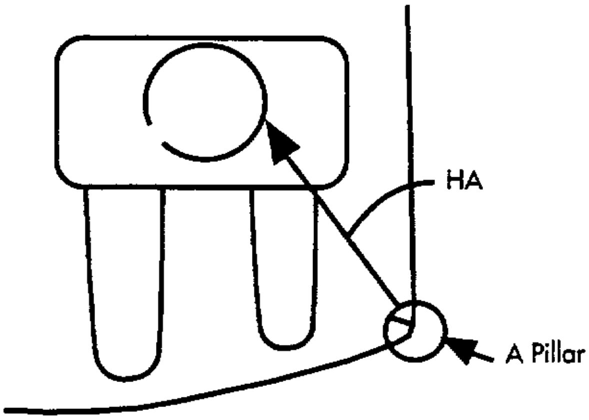


NR: Tip of Dummy's nose to top rear surface of Steering Wheel.
NH: Tip of Dummy's nose to centre of Steering Column Hub.

EA = Head Target to A pillar
HH = Head to Windshield Header
HW = Head to Windshield
CD = Chest to Dash
CS = Chest to Steering Wheel
KD = Knees to Dash
HR = Head to Side Roof
HS = Head to Side Window
AD = Arm to Door
HD = Hip to Door
KK = Knee to Knee

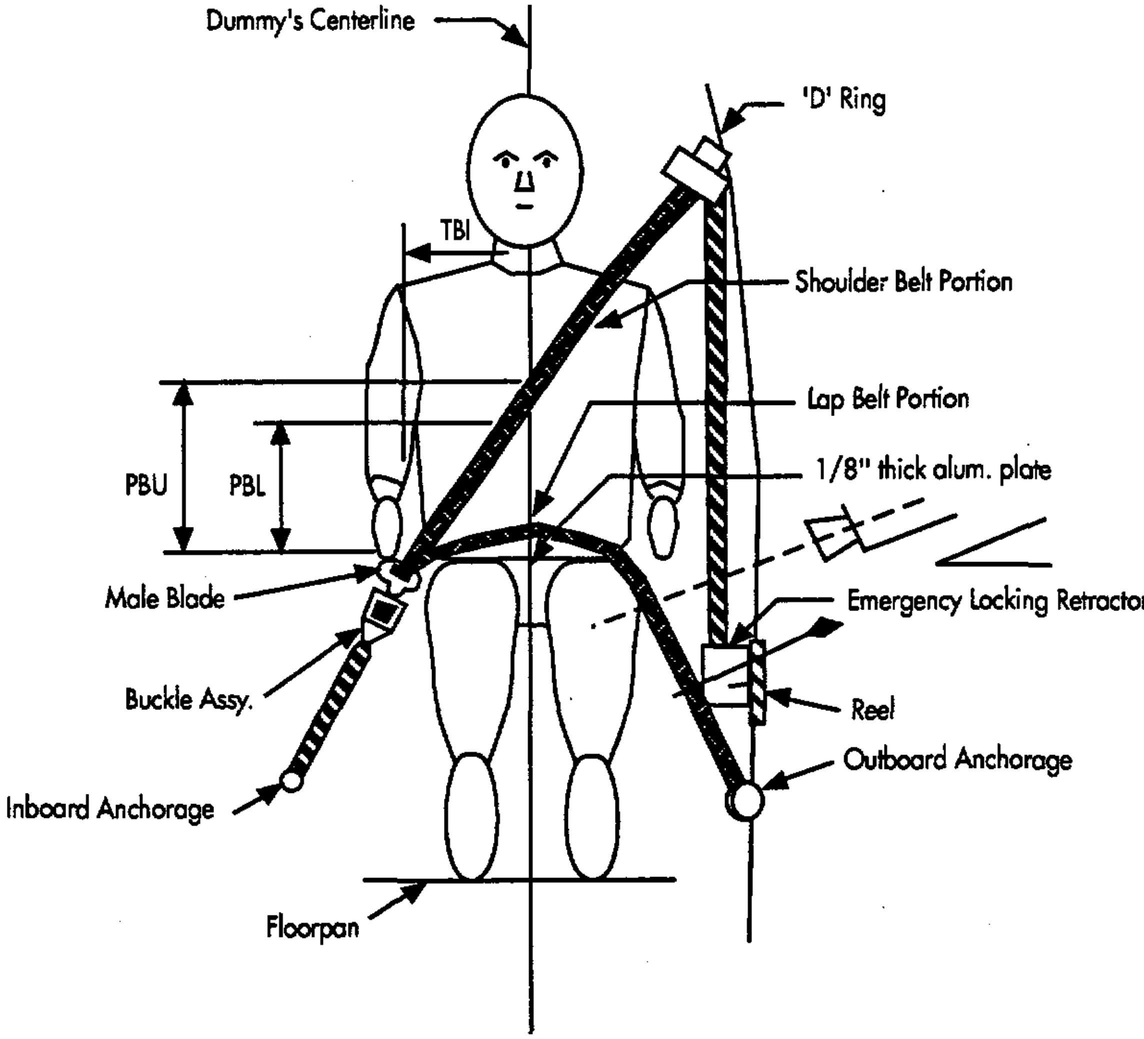
Torso and seat back angles are relative to vertical.

H: 'H' POINT TO REFERENCE TARGET/HORIZONTAL
V: 'H' POINT TO REFERENCE TARGET/VERTICAL
AA: ANKLE TO ANKLE INNER EDGES



	Driver	Passenger
HR	131	136
HS	N/A	N/A
AD	133	127
HD	210	213
KK	270	270
AA	180	160
EA	277	277

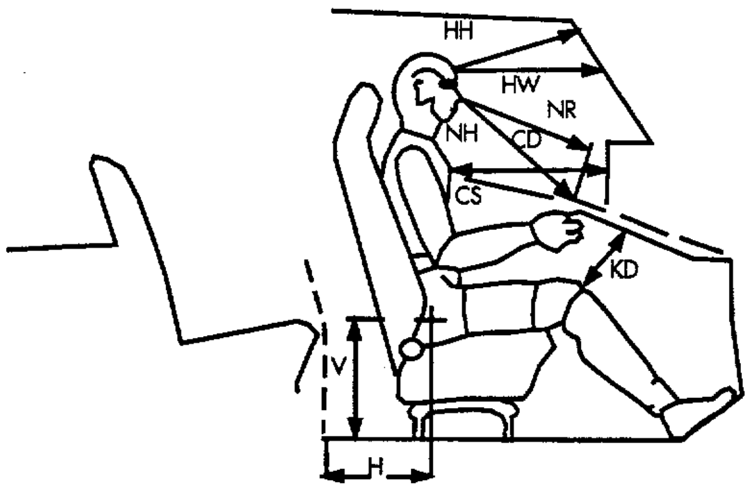
SEAT BELT POSITIONING DATA



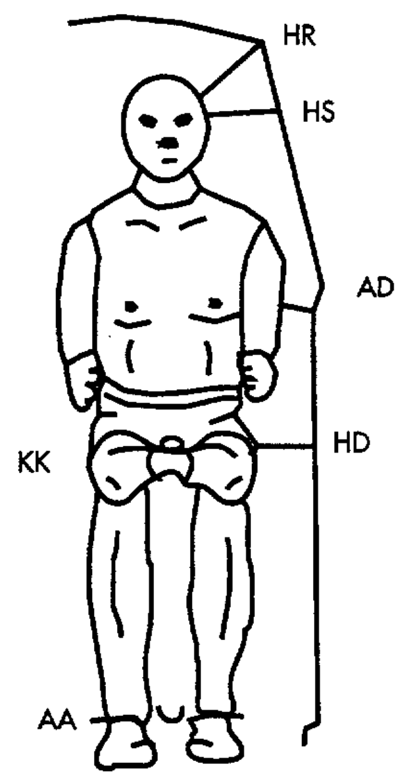
FRONT VIEW OF DRIVER DUMMY

	Driver Dummy	Passenger Dummy
PSU: Top surface of alum. plate to belt upper edge	297	297
PSL: Top surface of alum. plate to belt lower edge	225	225
TBI: Vertical centerline of 50 percentile dummy to intersection of upper torso belt to lap belt	237	232
KC: Dummy knee to camera lens	350	350
X: On board camera angle	-12°	-12°
SC: Sash belt/chest contact to sash point	320	320
TBIV: Vertical centreline of 50 percentile dummy to intersection of upper torso	20	20

DUMMY POSITIONING IN VEHICLE



	Driver		Passenger
HH	318		295
HW	450		428
CD	497		493
CS	315		N/A
KD	L- 146		L - 120
KD	R - 121		R - 129
Torso Angle	23.5 °		23 °
Seat Back Angle	25°		25°
NR -	382		N/A
NH	418		N/A
V	155		158
H	143		153

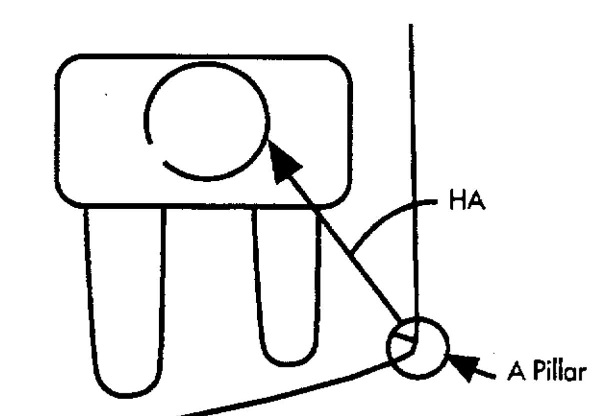


NR: Tip of Dummy's nose to top rear surface of Steering Wheel.
NH: Tip of Dummy's nose to centre of Steering Column Hub.

EA = Head Target to A pillar
HH = Head to Windshield Header
HW = Head to Windshield
CD = Chest to Dash
CS = Chest to Steering Wheel
KD = Knees to Dash
HR = Head to Side Roof
HS = Head to Side Window
AD = Arm to Door
HD = Hip to Door
KK = Knee to Knee

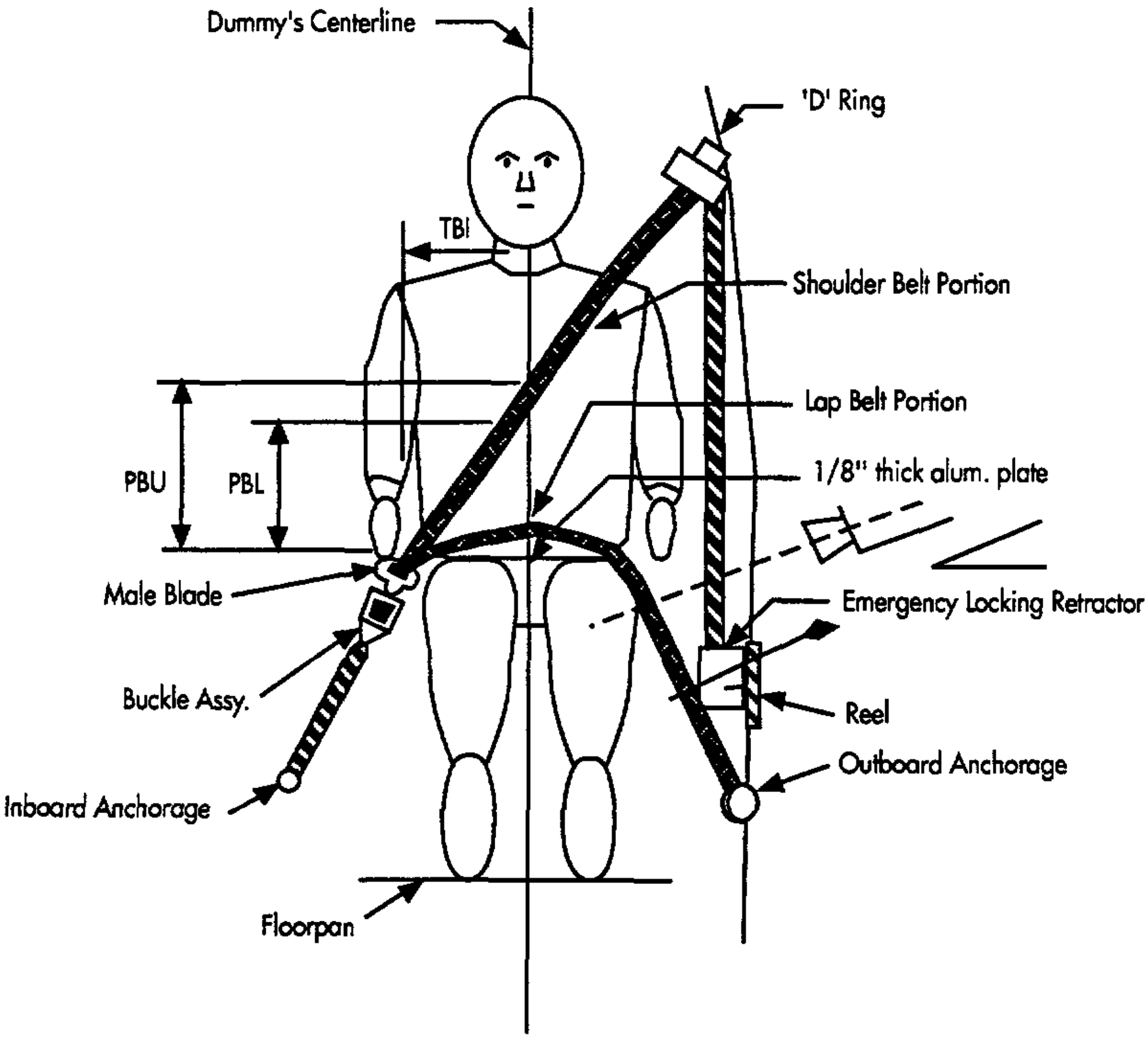
Torso and seat back angles are relative to vertical.

H: 'H' POINT TO REFERENCE TARGET/HORIZONTAL
V: 'H' POINT TO REFERENCE TARGET/VERTICAL
AA: ANKLE TO ANKLE INNER EDGES



	Driver	Passenger
HR	135	137
HS	N/A	N/A
AD	63	40
HD	220	210
KK	270	270
AA	165	160
EA	326	306

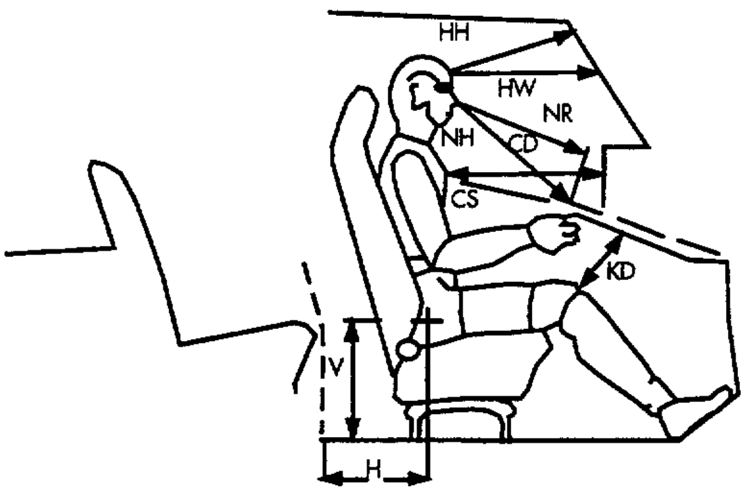
SEAT BELT POSITIONING DATA



FRONT VIEW OF DRIVER DUMMY

	Driver Dummy	Passenger Dummy
PSU: Top surface of alum. plate to belt upper edge	300	330
PSL: Top surface of alum. plate to belt lower edge	225	250
TBI: Vertical centerline of 50 percentile dummy to intersection of upper torso belt to lap belt	235	215
KC: Dummy knee to camera lens	355	350
X: On board camera angle	-20°	-20°
SC: Sash belt/chest contact to sash point	340	315
TBIV: Vertical centreline of 50 percentile dummy to intersection of upper torso	10	15

DUMMY POSITIONING IN VEHICLE



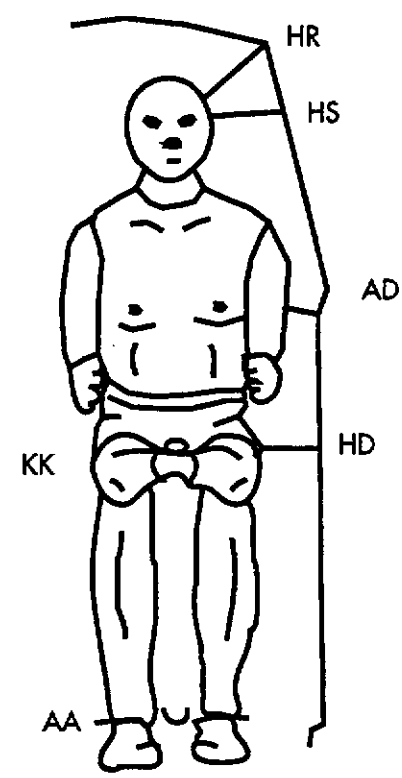
	Driver	Passenger
HH	237	238
HW	397	408
CD	470	517
CS	305	N/A
KD	L - 133	L - 133
KD	R - 96	R - 139
Torso Angle	23.5 °	22.5 °
Seat Back Angle	25°	25°
NR -	369	N/A
NH	399	N/A
V	148	138
H	138	140

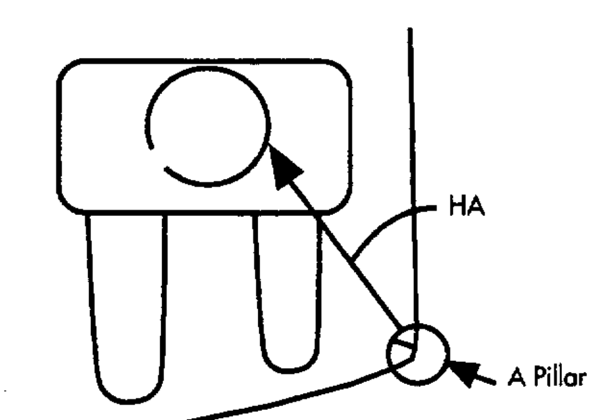
NR: Tip of Dummy's nose to top rear surface of Steering Wheel.
NH: Tip of Dummy's nose to centre of Steering Column Hub.

EA = Head Target to A pillar
HH = Head to Windshield Header
HW = Head to Windshield
CD = Chest to Dash
CS = Chest to Steering Wheel
KD = Knees to Dash
HR = Head to Side Roof
HS = Head to Side Window
AD = Arm to Door
HD = Hip to Door
KK = Knee to Knee

Torso and seat back angles are relative to vertical.

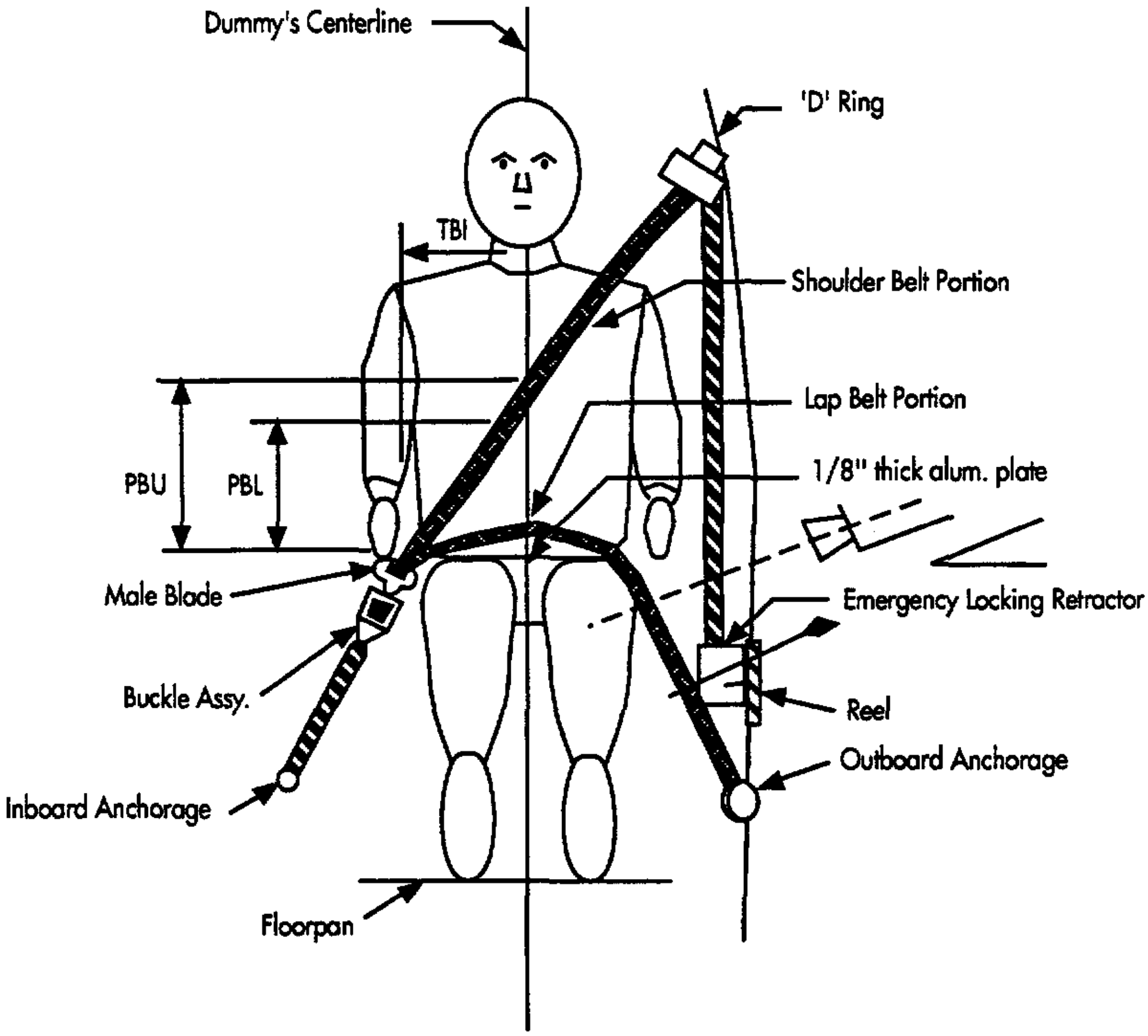
H: 'H' POINT TO REFERENCE TARGET/HORIZONTAL
V: 'H' POINT TO REFERENCE TARGET/VERTICAL
AA: ANKLE TO ANKLE INNER EDGES





	Driver	Passenger
HR	124	142
HS	N/A	N/A
AD	117	106
HD	205	200
KK	270	270
AA	165	150
EA	249	248

SEAT BELT POSITIONING DATA



FRONT VIEW OF DRIVER DUMMY

	Driver Dummy	Passenger Dummy
PSU: Top surface of alum. plate to belt upper edge	325	320
PSL: Top surface of alum. plate to belt lower edge	250	240
TBI: Vertical centerline of 50 percentile dummy to intersection of upper torso belt to lap belt	215	215
KC: Dummy knee to camera lens	330	325
X: On board camera angle	-19°	-19°
SC: Sash belt/chest contact to sash point	375	335
TBIV: Vertical centreline of 50 percentile dummy to intersection of upper torso belt to lap belt - vertical height	40	50

Appendix 4

Phase 1 Test Vehicle Photographs

Appendix 4

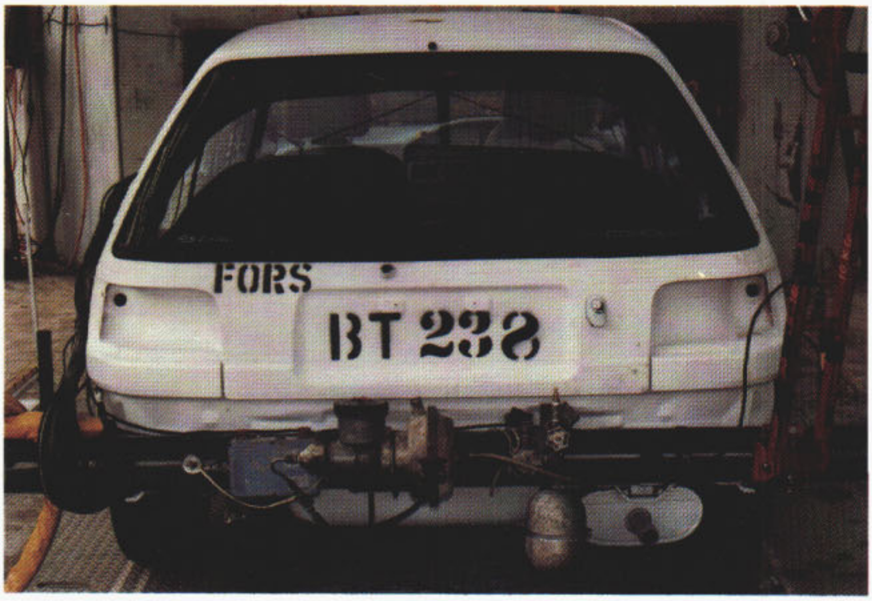
This appendix contains photographs of each of the test vehicles depicting:

- Vehicle during crash sequence;
- Pre-test and post-test side and overhead views of the vehicle. These views also show the on-board high speed cameras in position.
- Pre-test and post-test views of the Driver and Passenger Hybrid III Dummies.

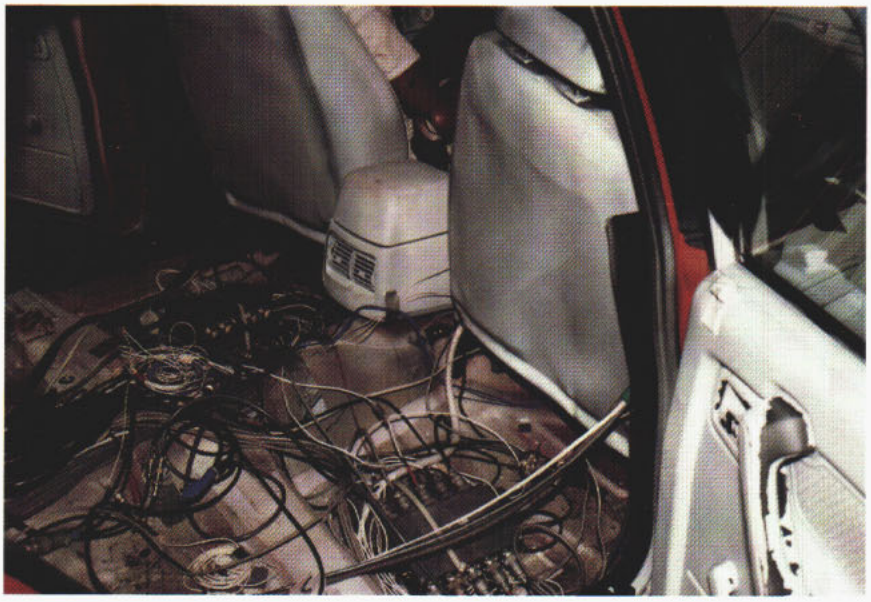
It also contains photographs of a typical vehicle set-up for data acquisition, brake abort system and speed measuring device.

Typical set-up.

Abort system mounted on centre of crossbar. Fifth wheel mounted on right hand side. Umbilical cord (yellow sheath) for transfer of data on left hand side.

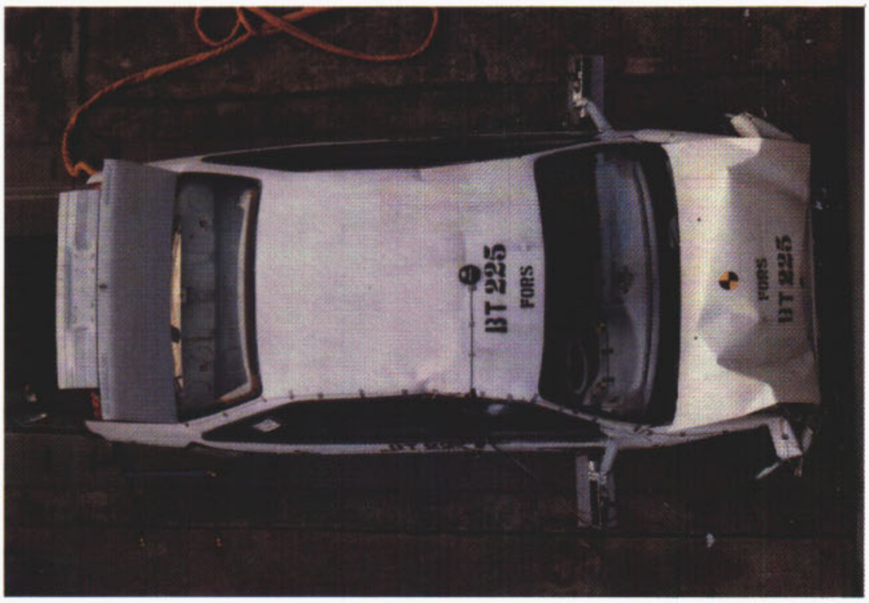


Instrumentation terminal blocks.

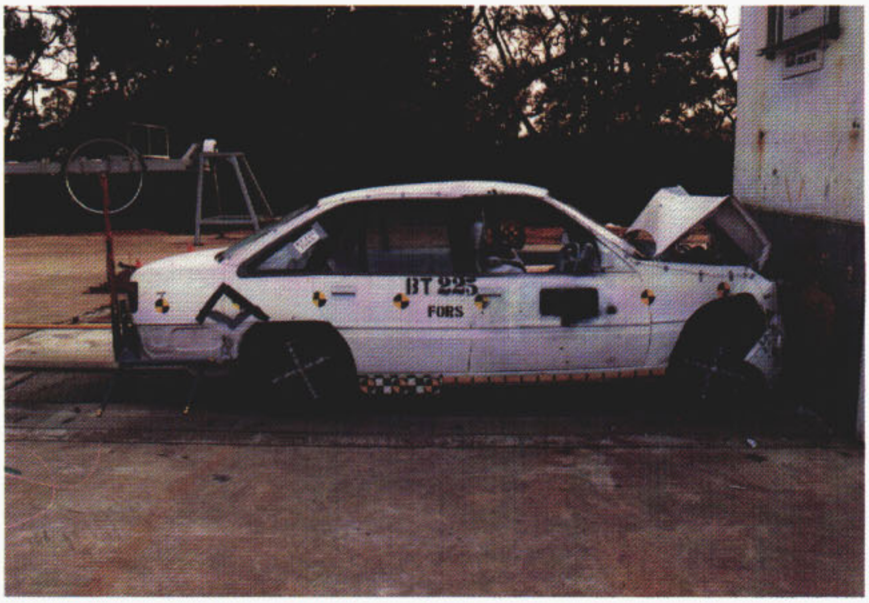


BT225

BT225 — overhead view

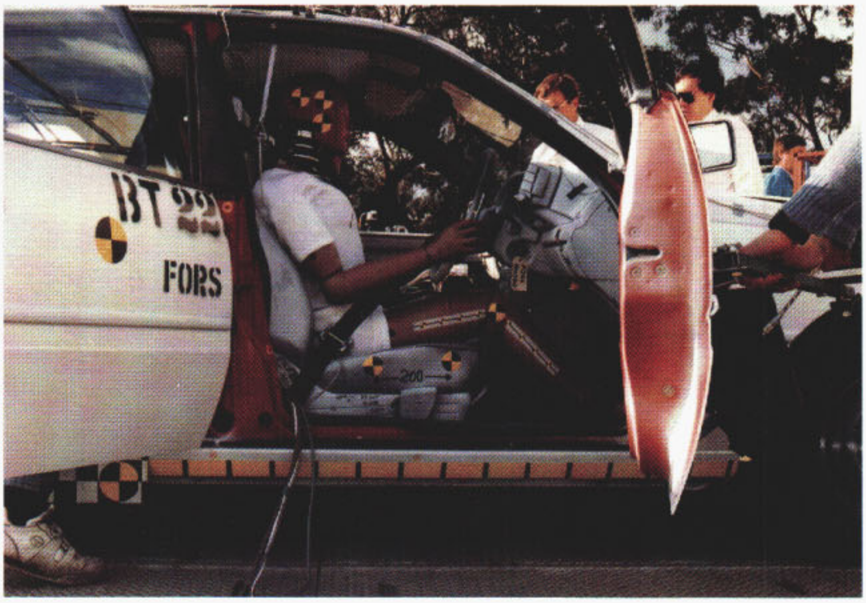


BT225 — driver's side view



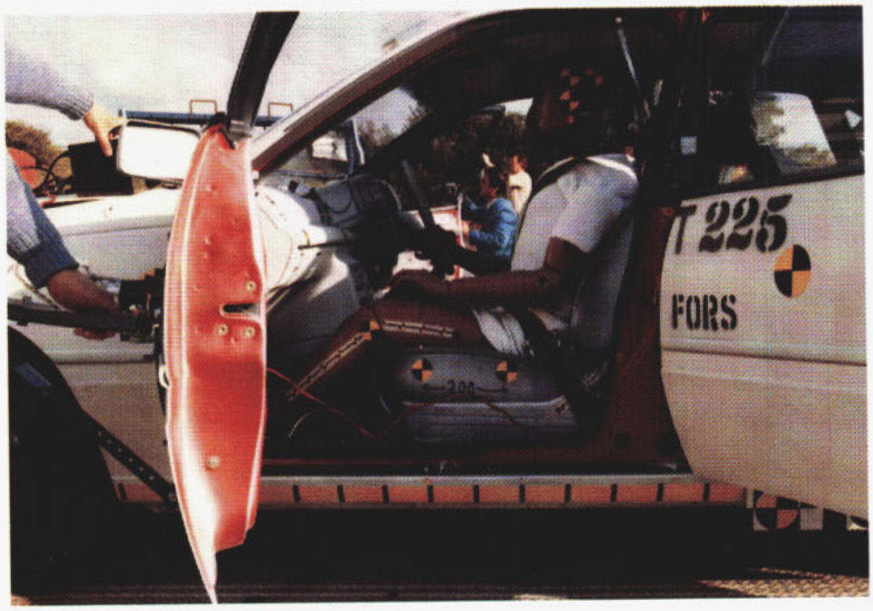
BT225 — passenger's side view

BT225 — pre-test driver's side

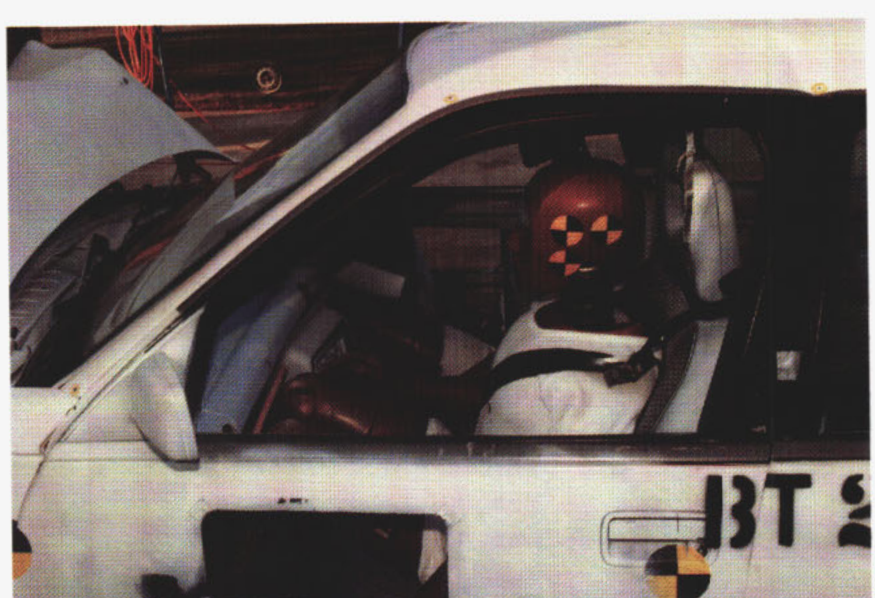


BT225 — post-test driver's side

BT225 — pre-test passenger's side

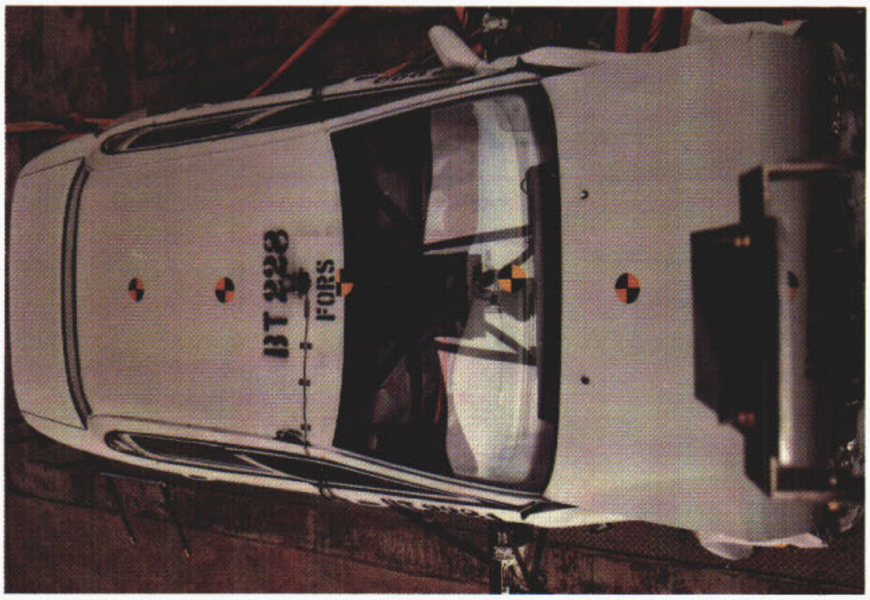


BT225 — post-test passenger's side



BT228

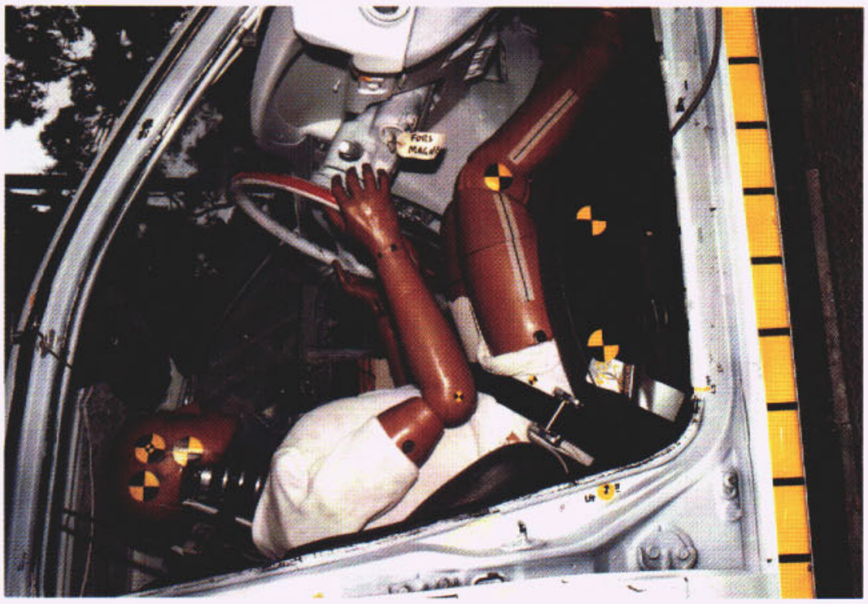
BT228 — overhead view



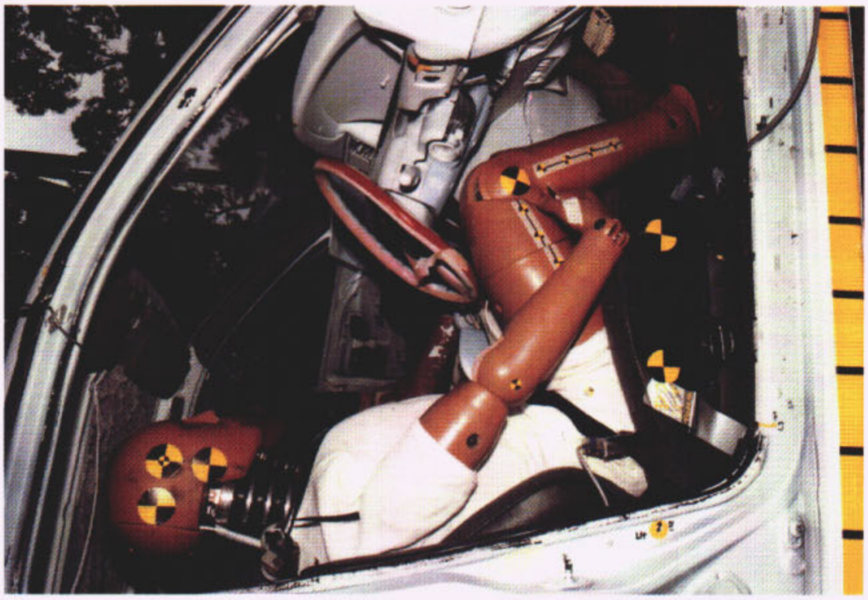
BT228 — driver's side view

BT228 — passenger's side view

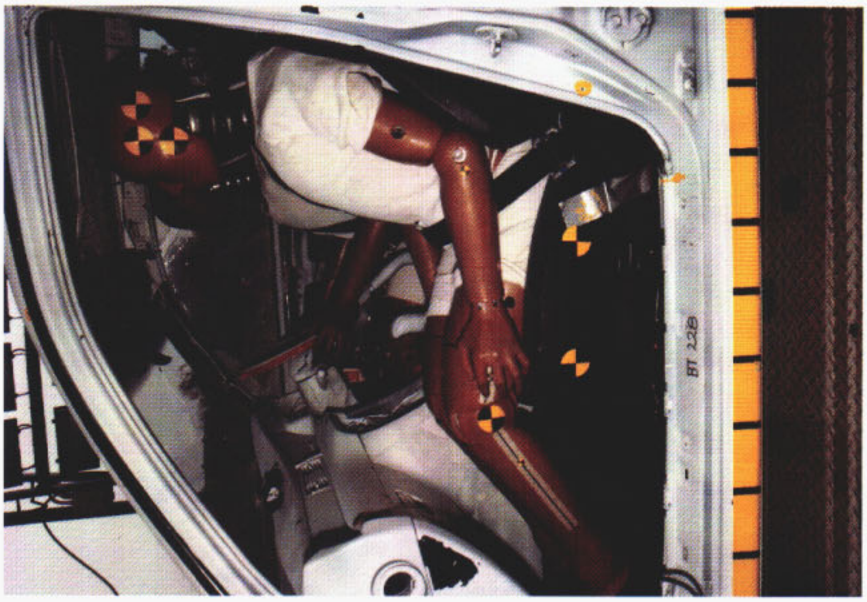
BT228 — pre-test driver's side



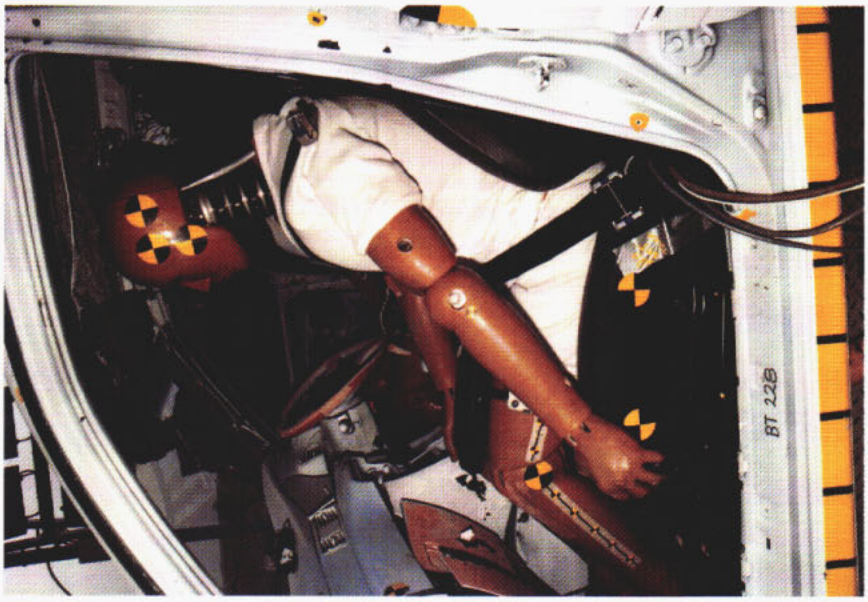
BT228 — post-test driver's side



BT228 — pre-test passenger's side

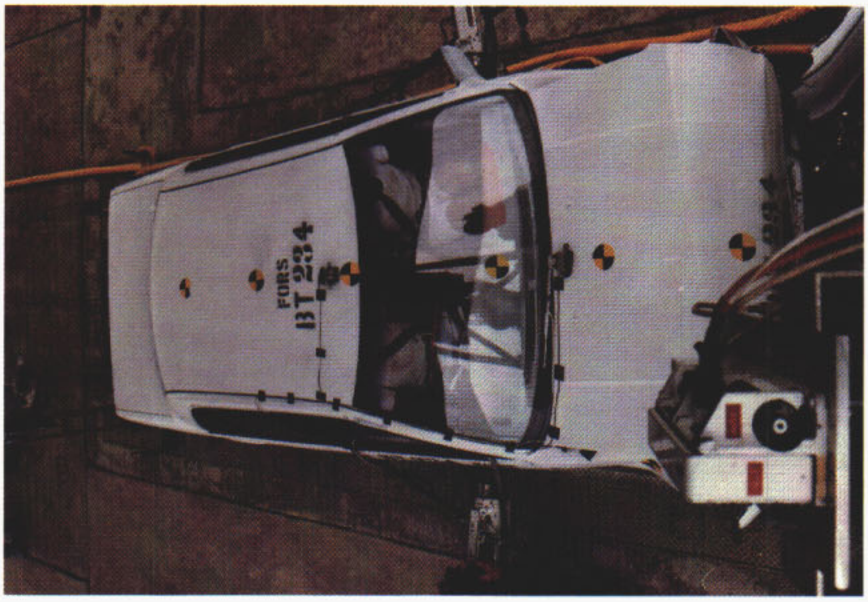


BT228 — post-test passenger's side



BT234

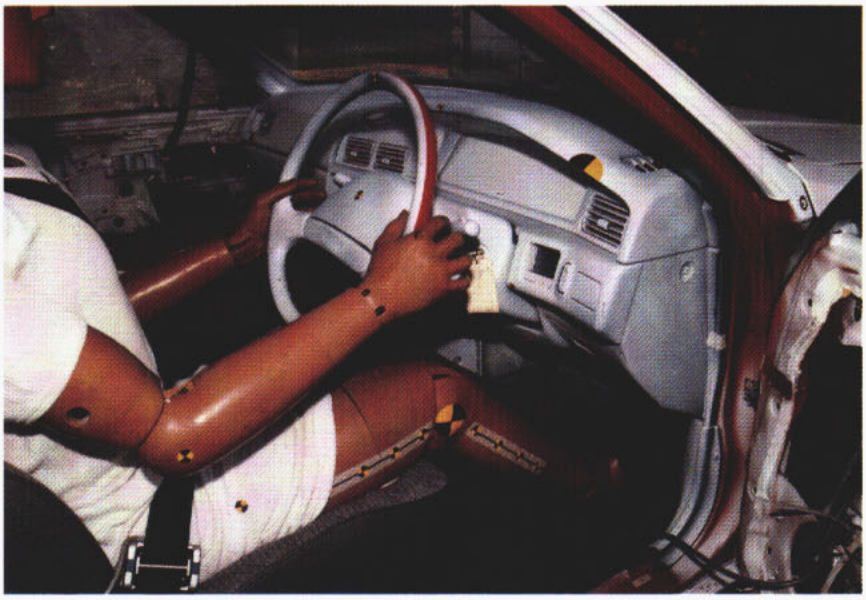
BT234 — overhead view



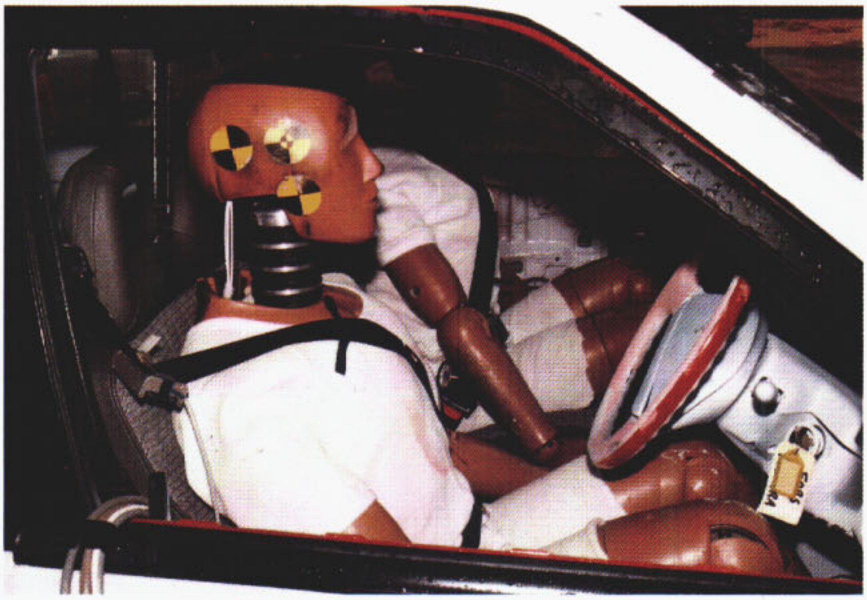
BT234 — driver's side view

BT234 — passenger's side view

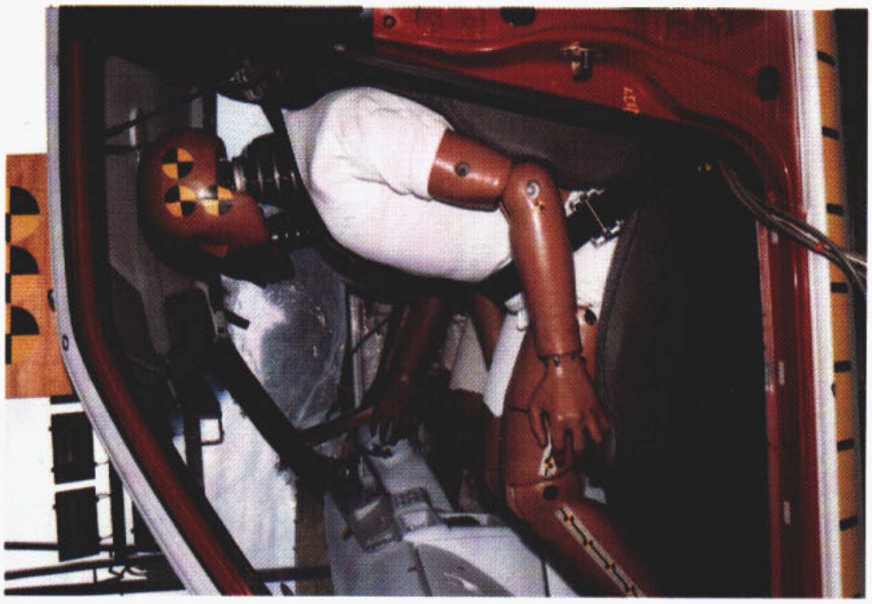
BT234 — pre-test driver's side



BT234 — post-test driver's side

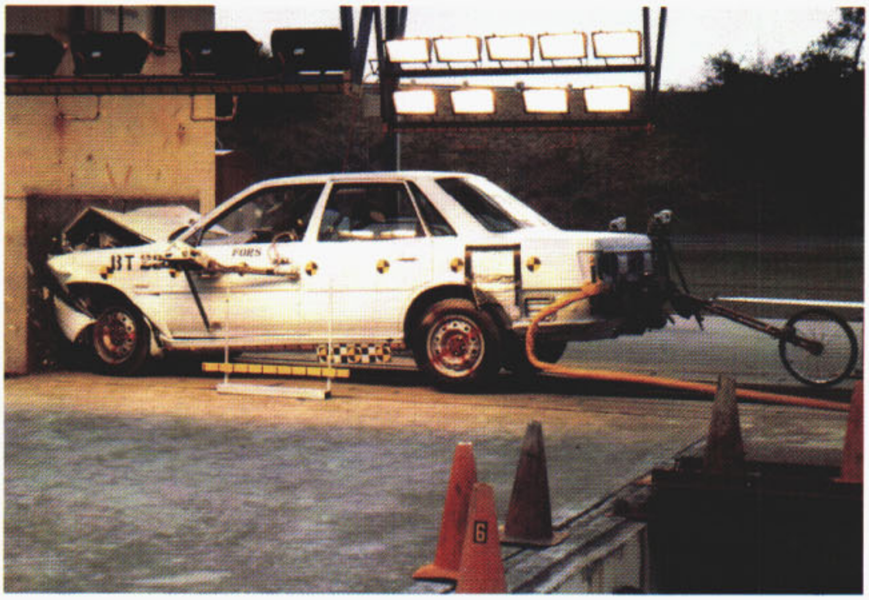


BT234 — pre-test passenger's side



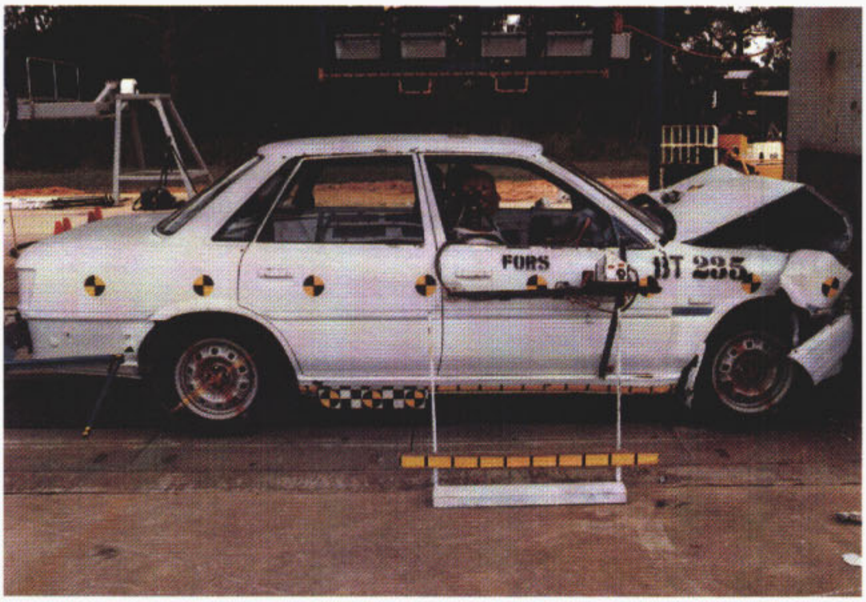
BT234 — post-test passenger's side

BT235

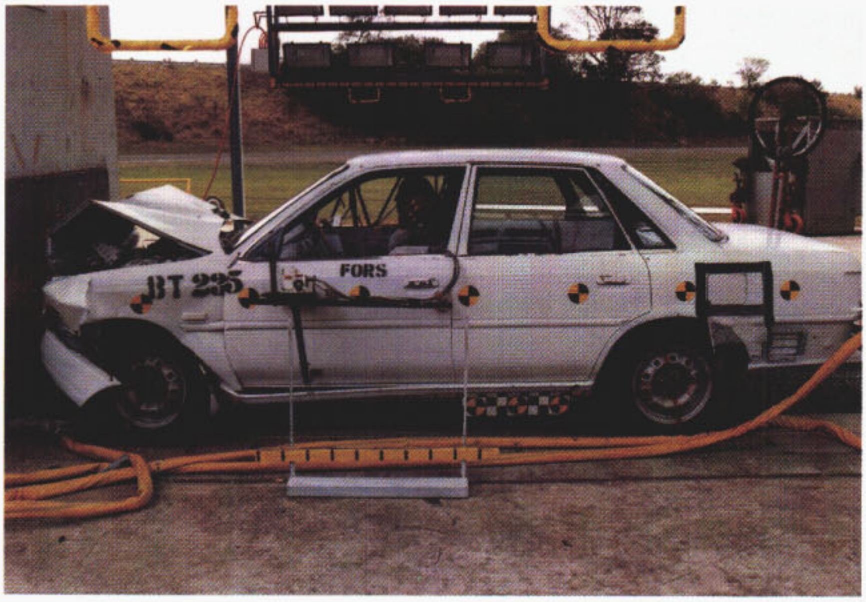


BT235 — overhead view

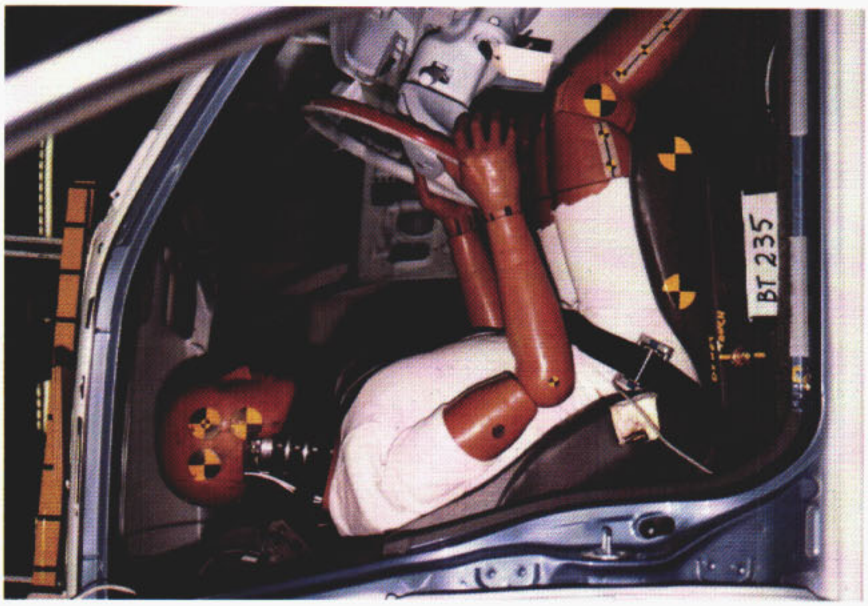
BT235 — driver's side view



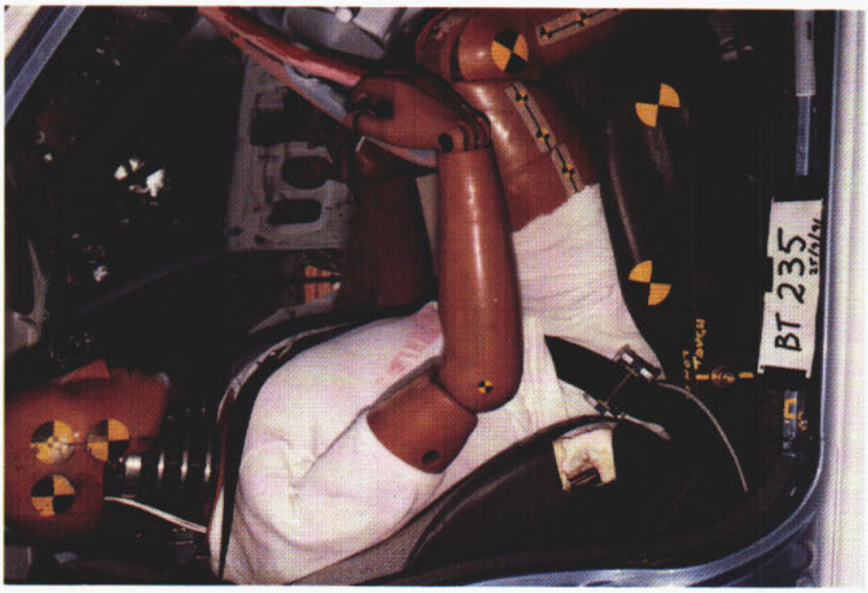
BT235 — passenger's side view



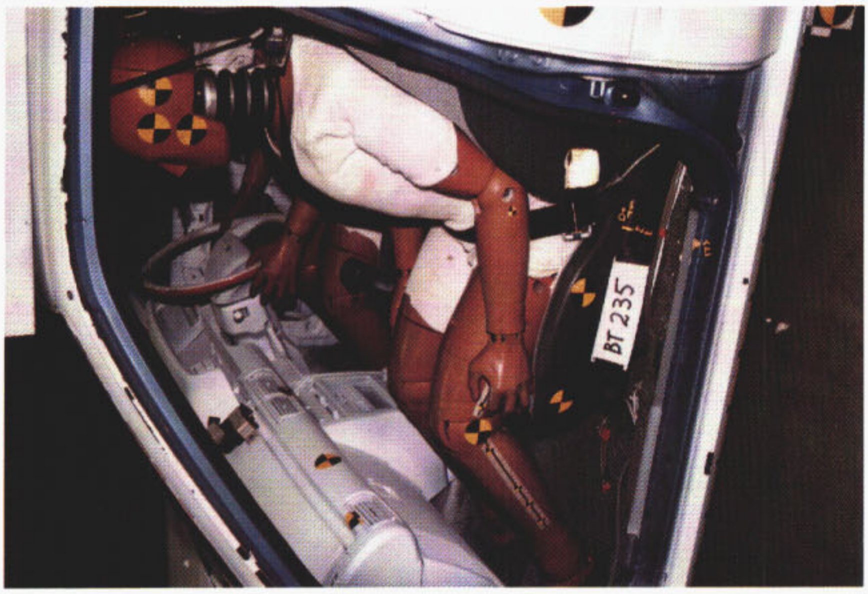
BT235 — pre-test driver's side



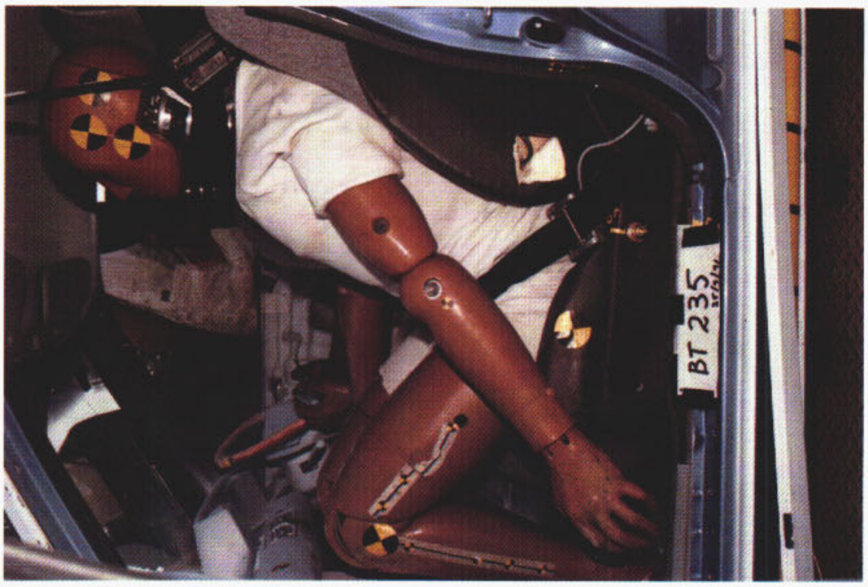
BT235 — post-test driver's side



BT235 — pre-test passenger's side

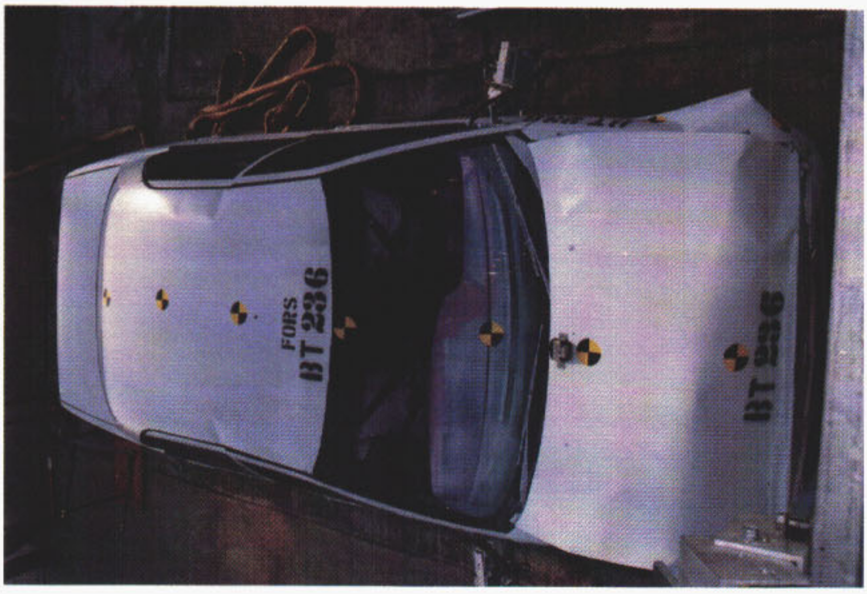


BT235 — post-test passenger's side

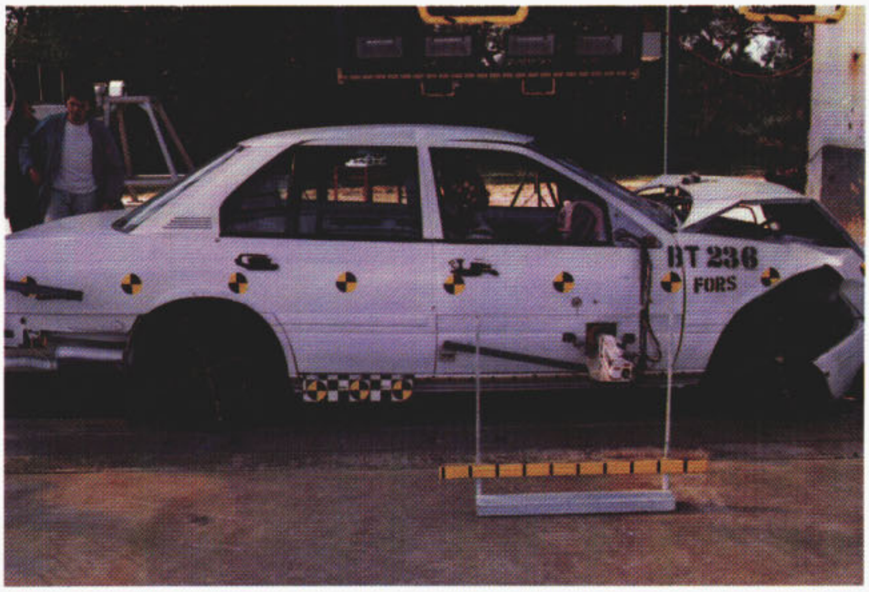


BT236

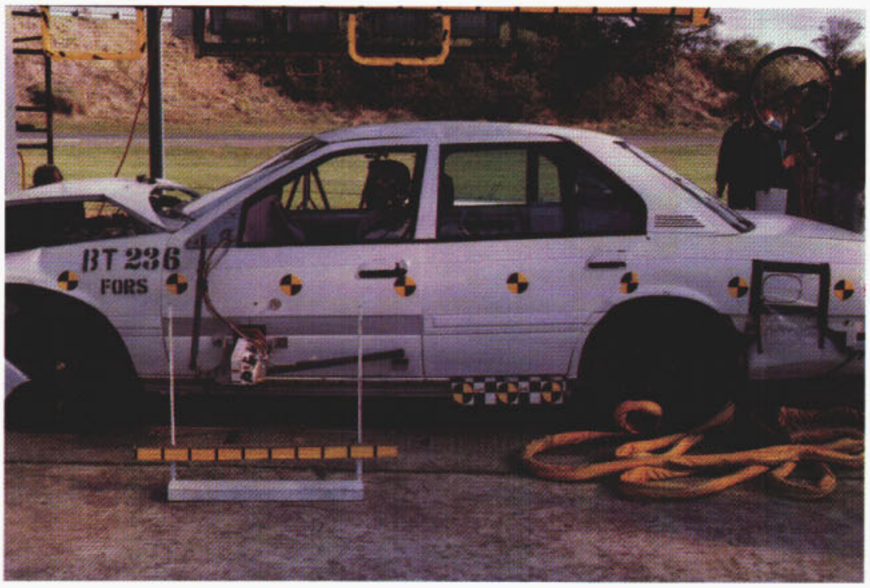
BT236 — overhead view



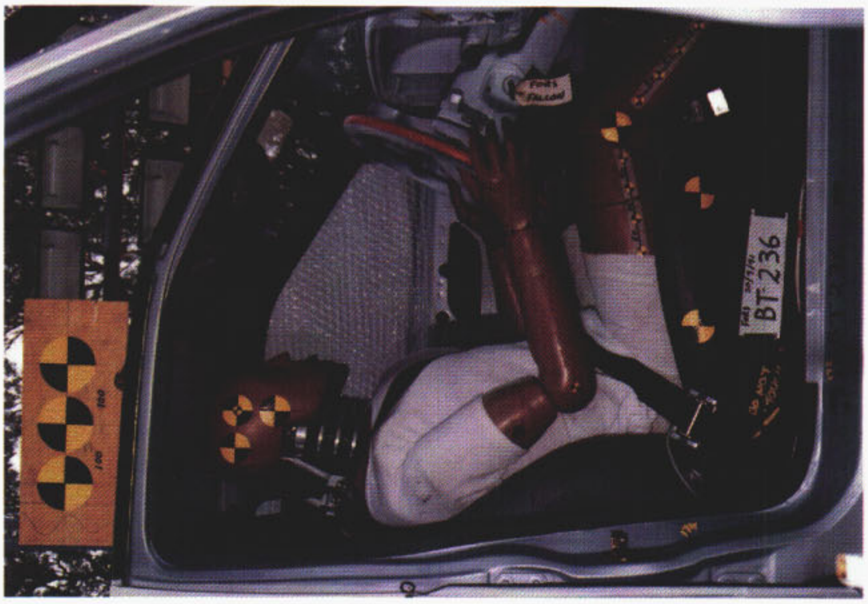
BT236 — driver's side view



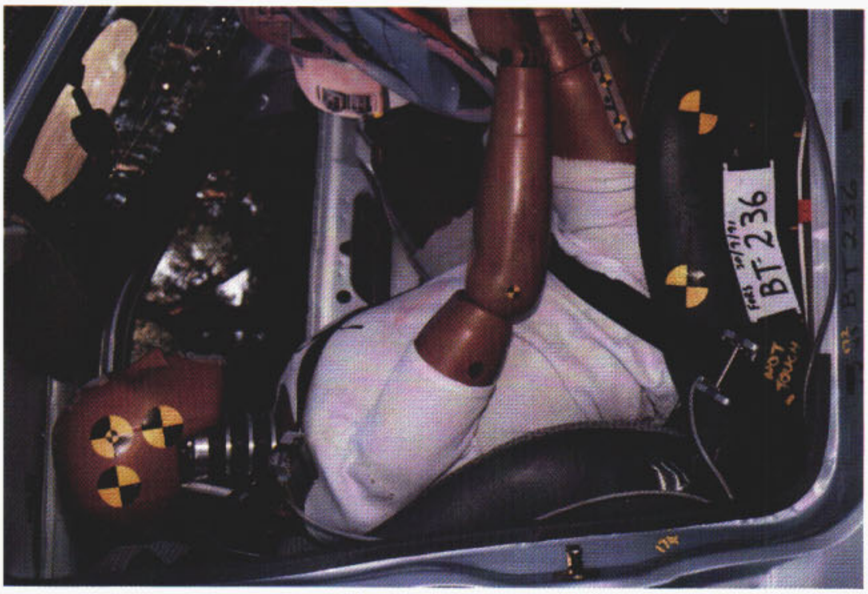
BT236 — passenger's side view



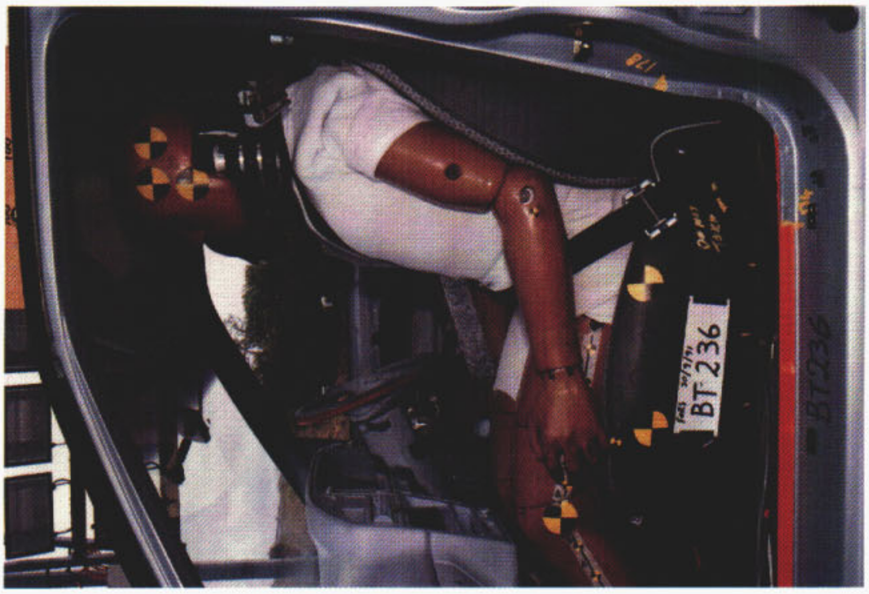
BT236 — pre-test driver's side



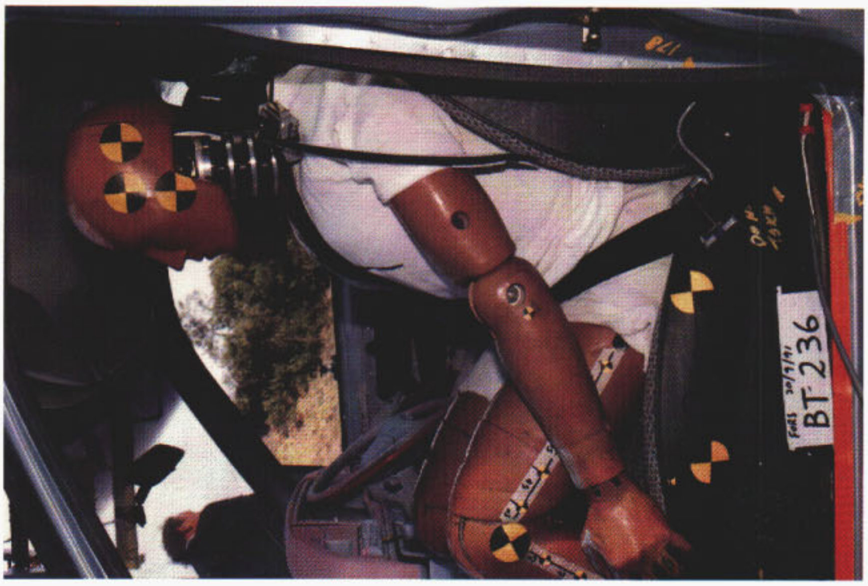
BT236 — post-test driver's side



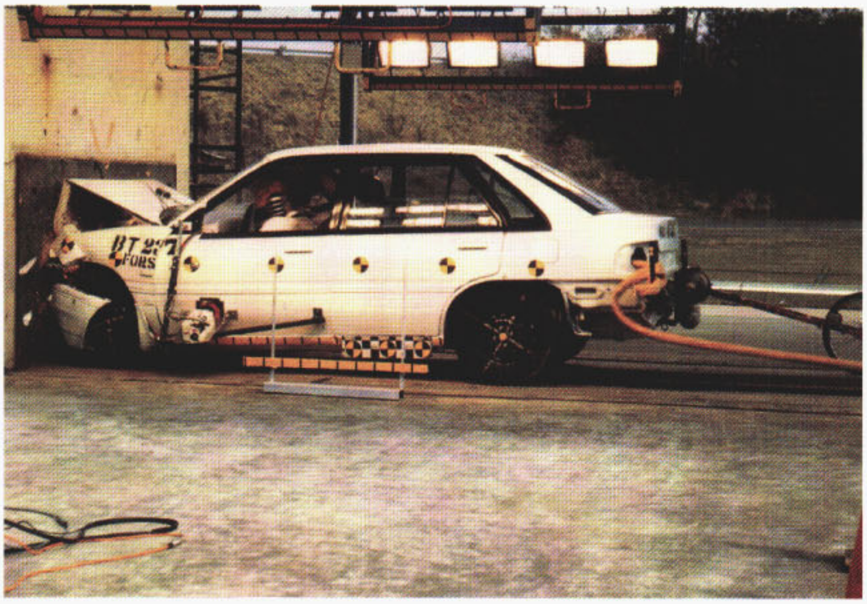
BT236 — pre-test passenger's side



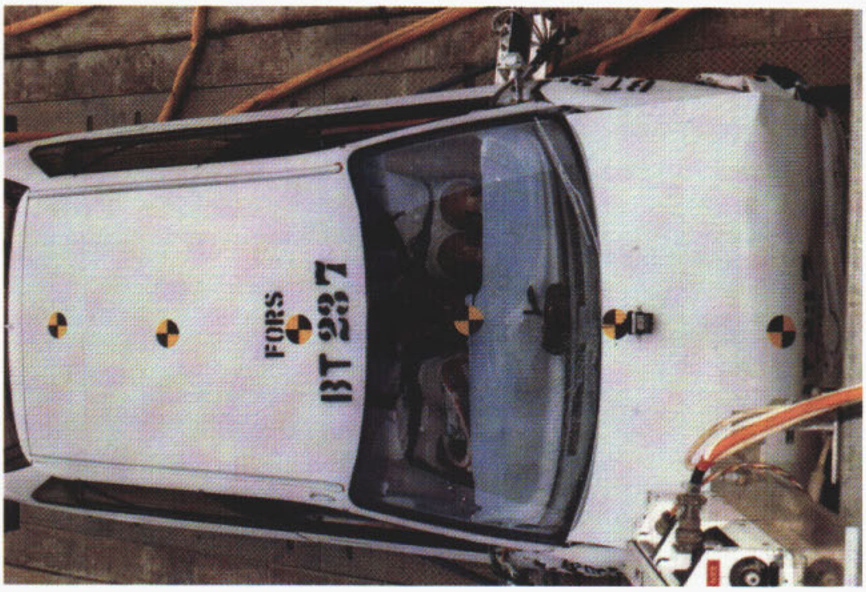
BT236 — post-test passenger's side



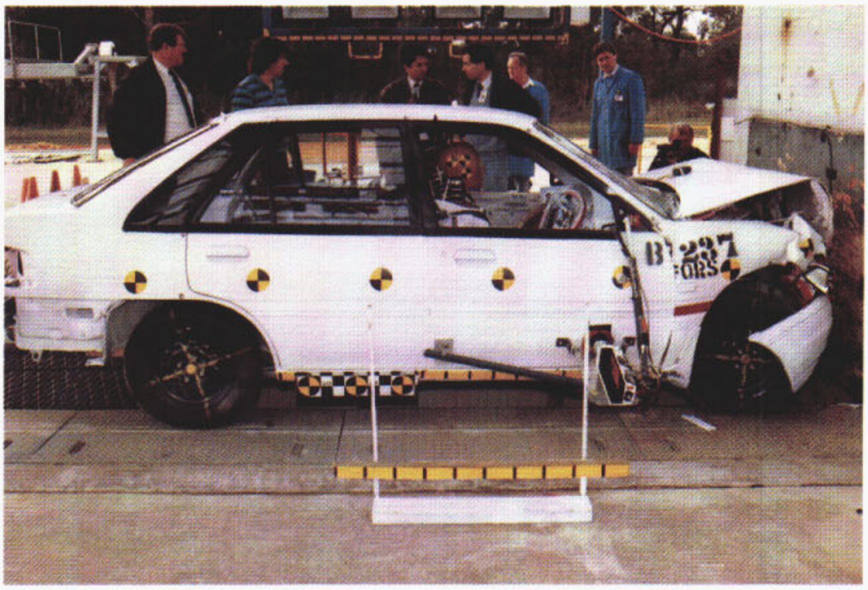
BT237



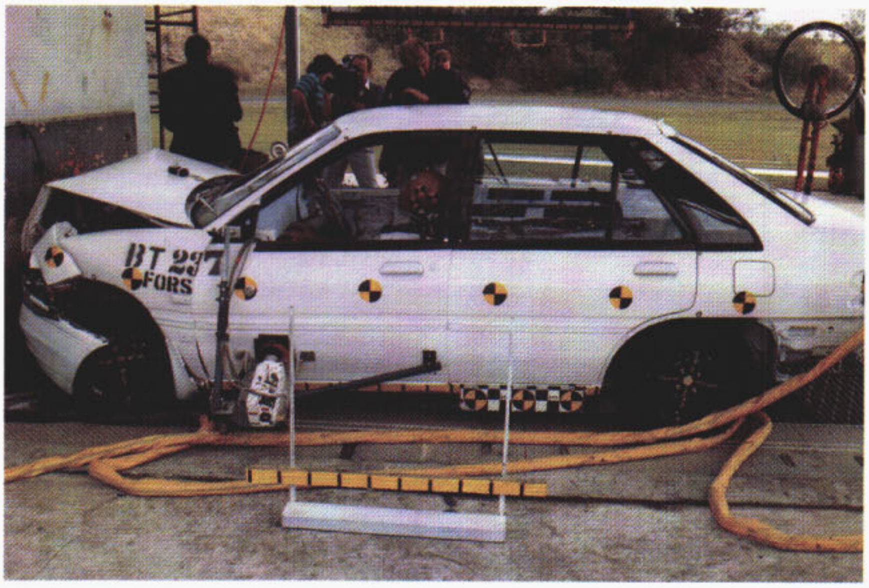
BT237 — overhead view



BT237 — driver's side view

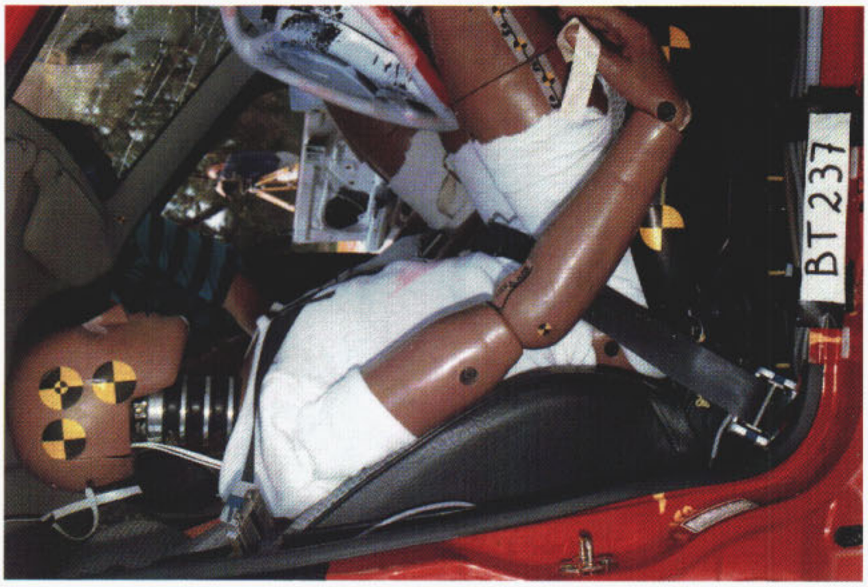


BT237 — passenger's side view

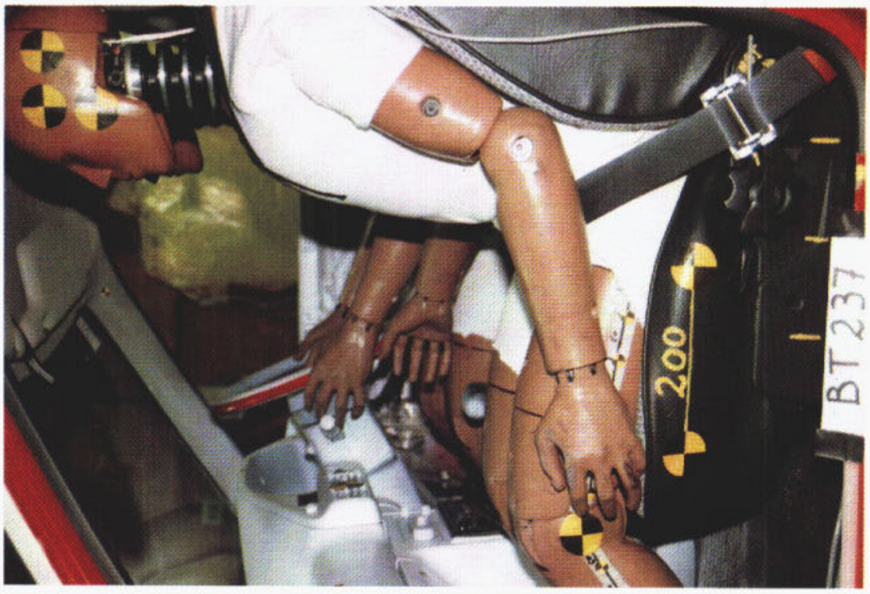


BT237 — pre-test driver's side

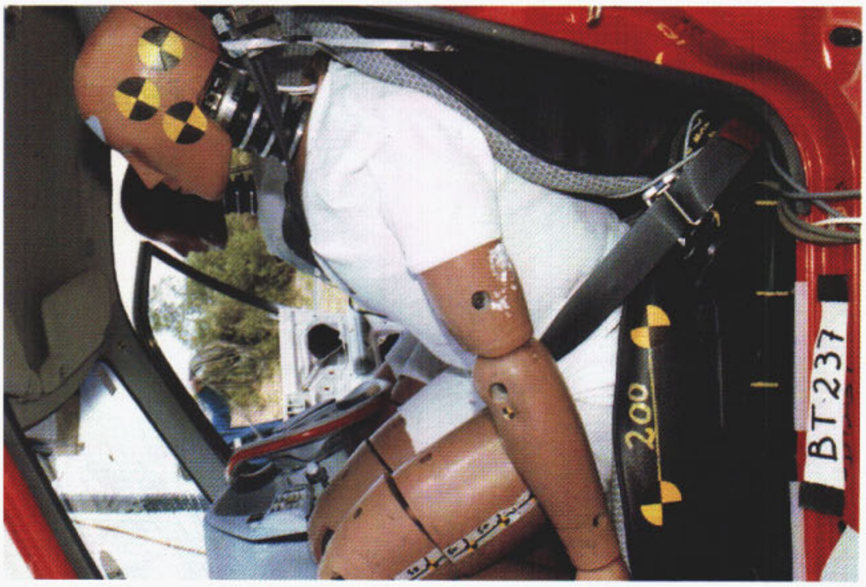
BT237 — post-test driver's side



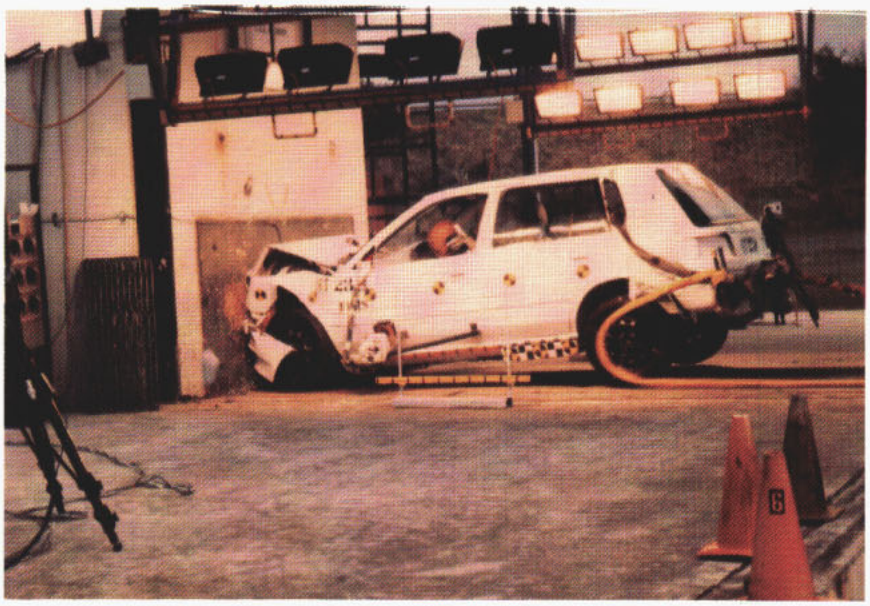
BT237 — pre-test passenger's side



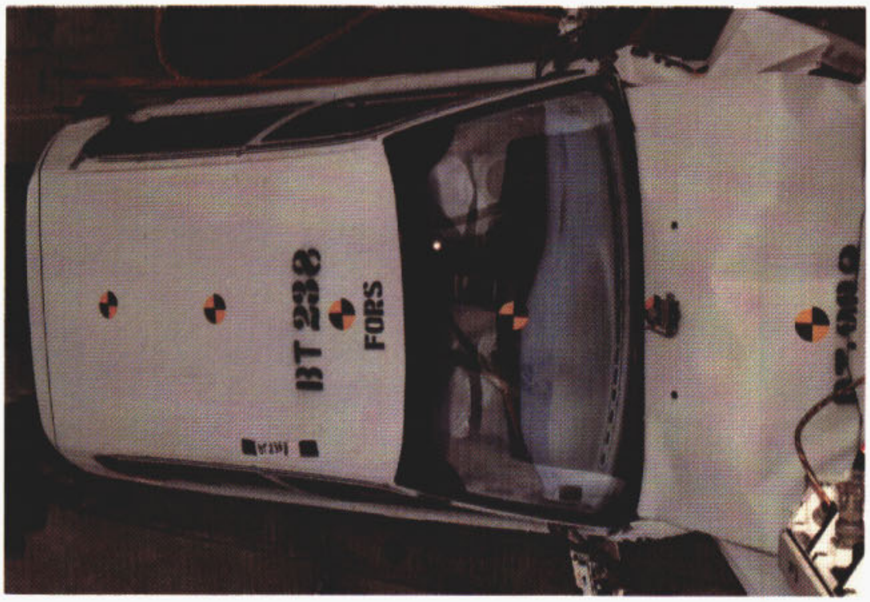
BT237 — post-test passenger's side



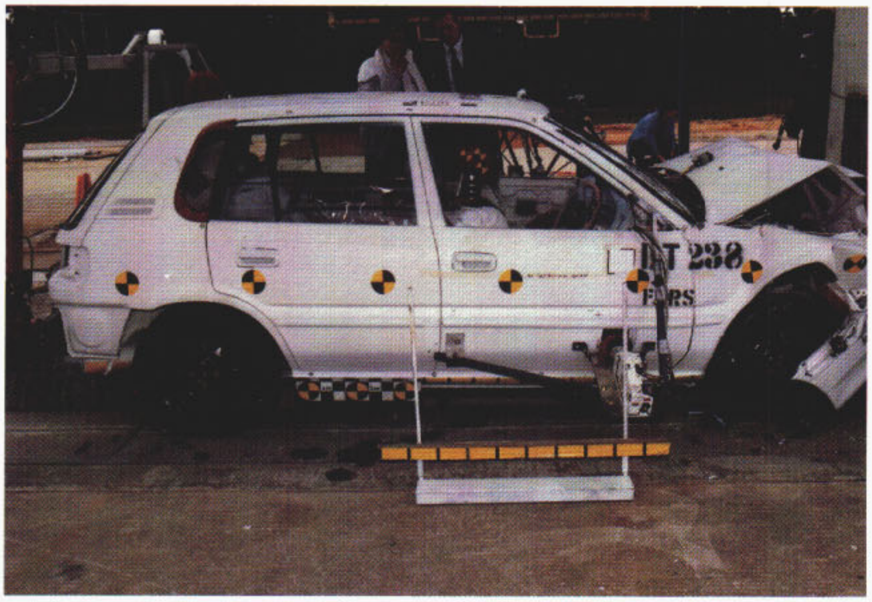
BT238



BT238 — overhead view

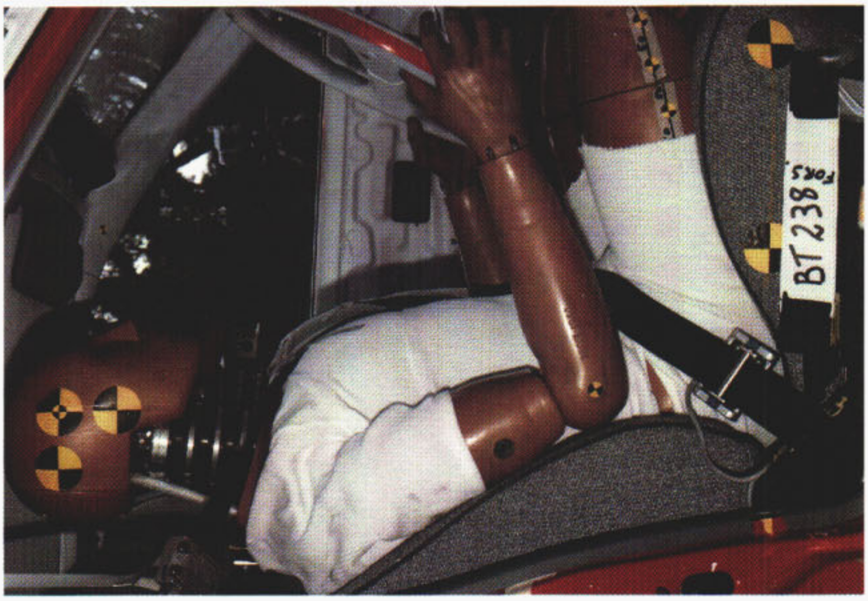


BT238 — driver's side view

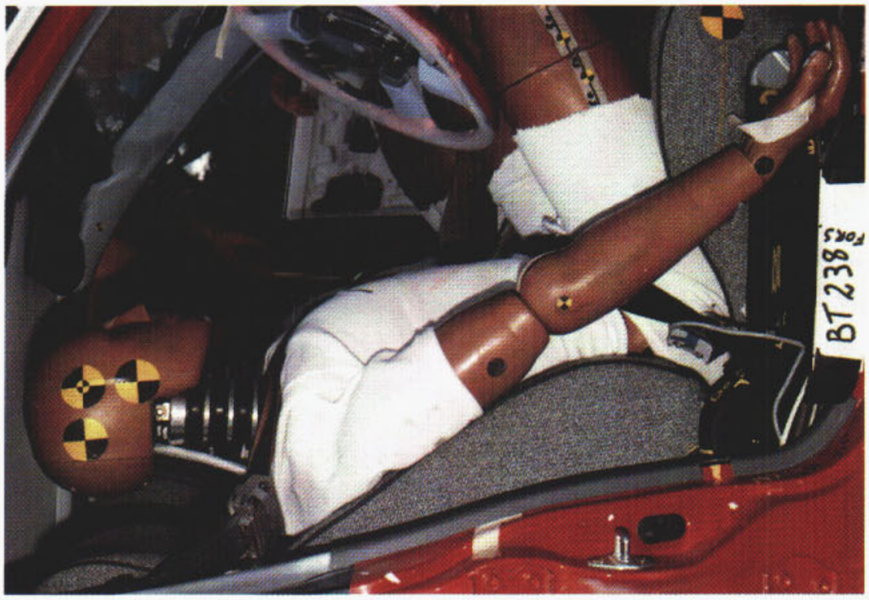


BT238 — passenger's side view

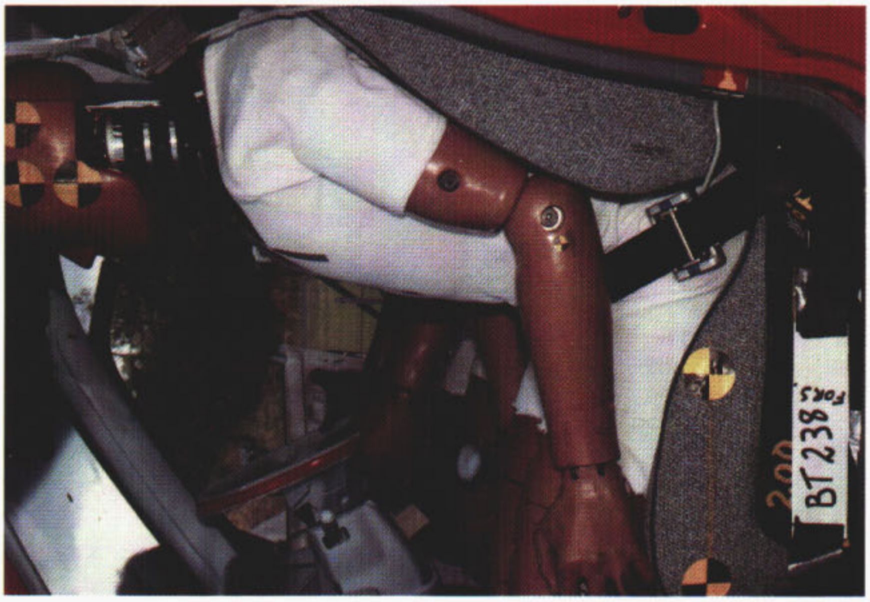
BT238 — pre-test driver's side



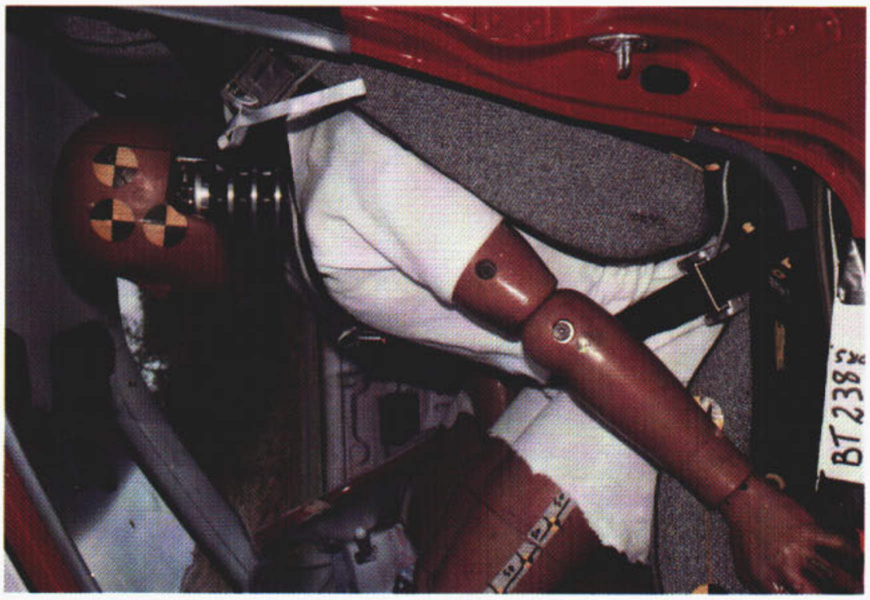
BT238 — post-test driver's side



BT238 — pre-test passenger's side

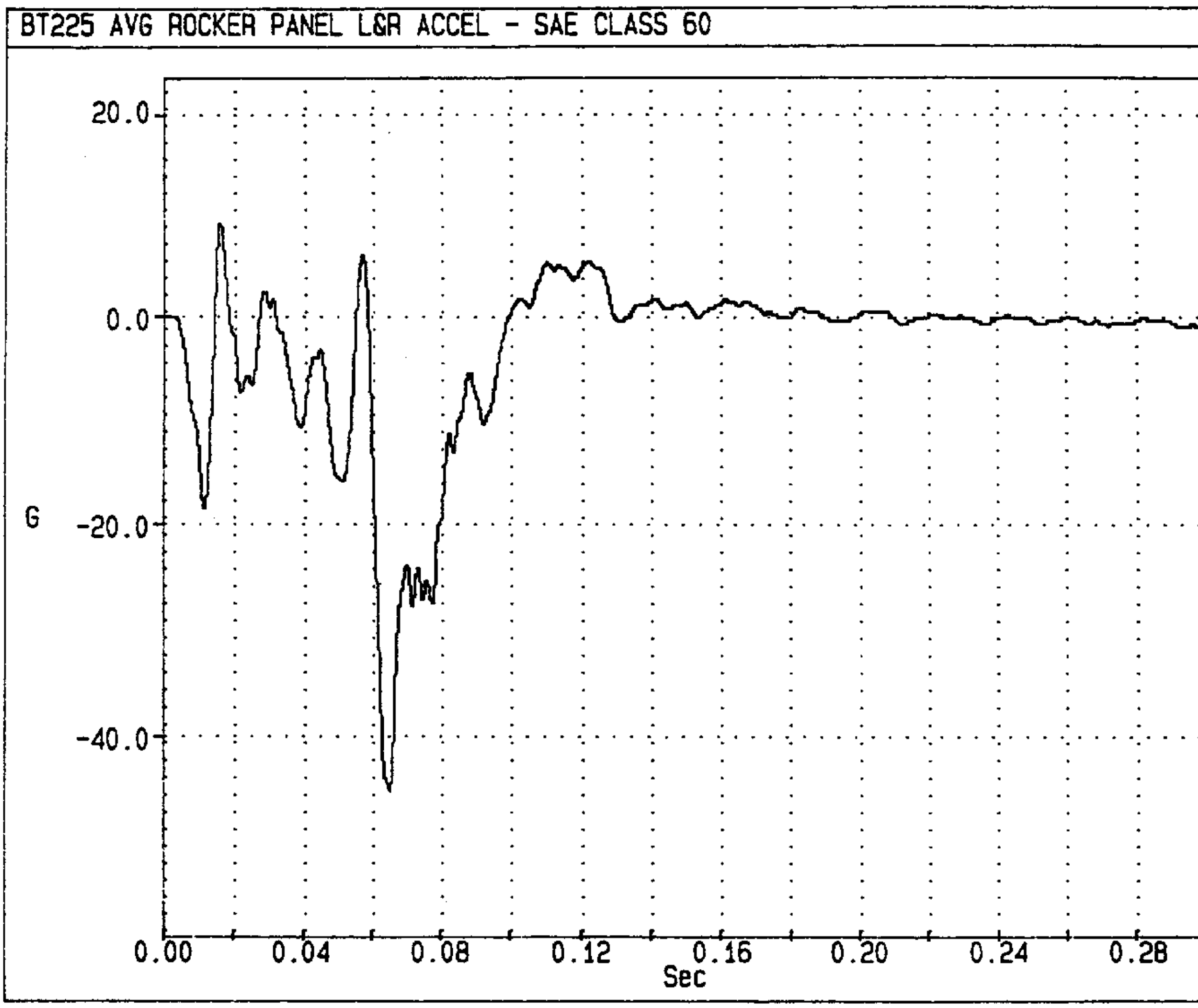


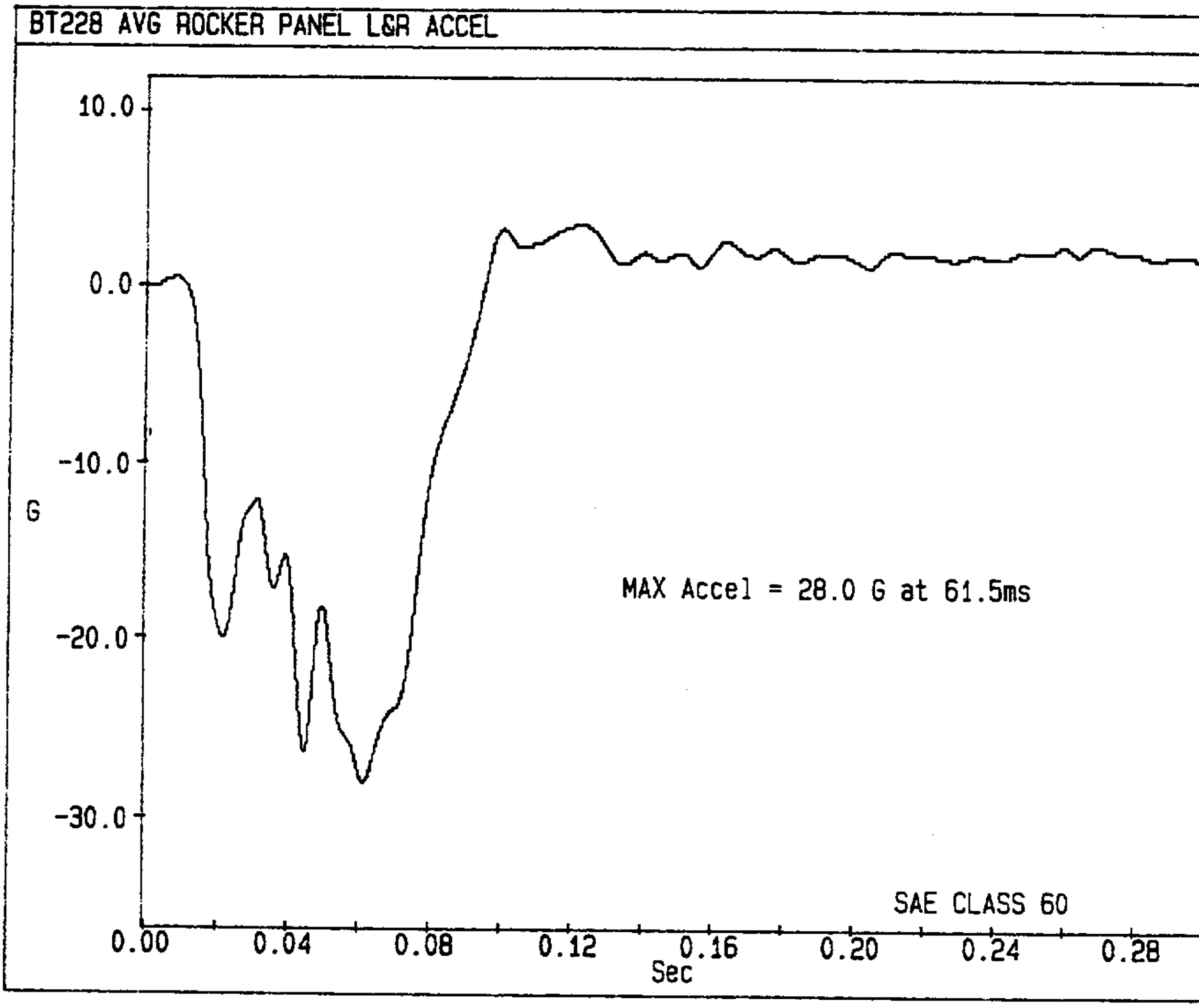
BT238 — post-test passenger's side

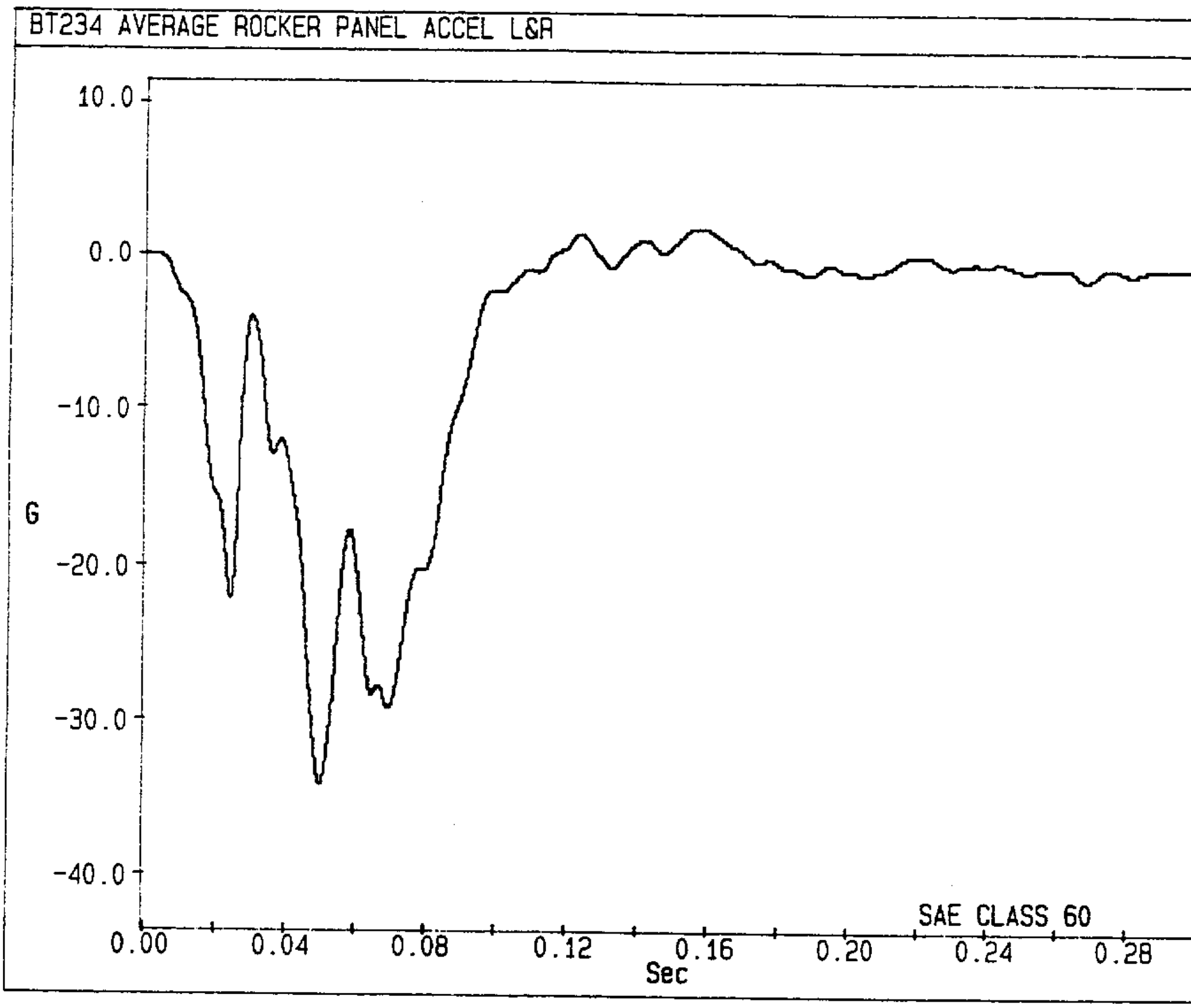


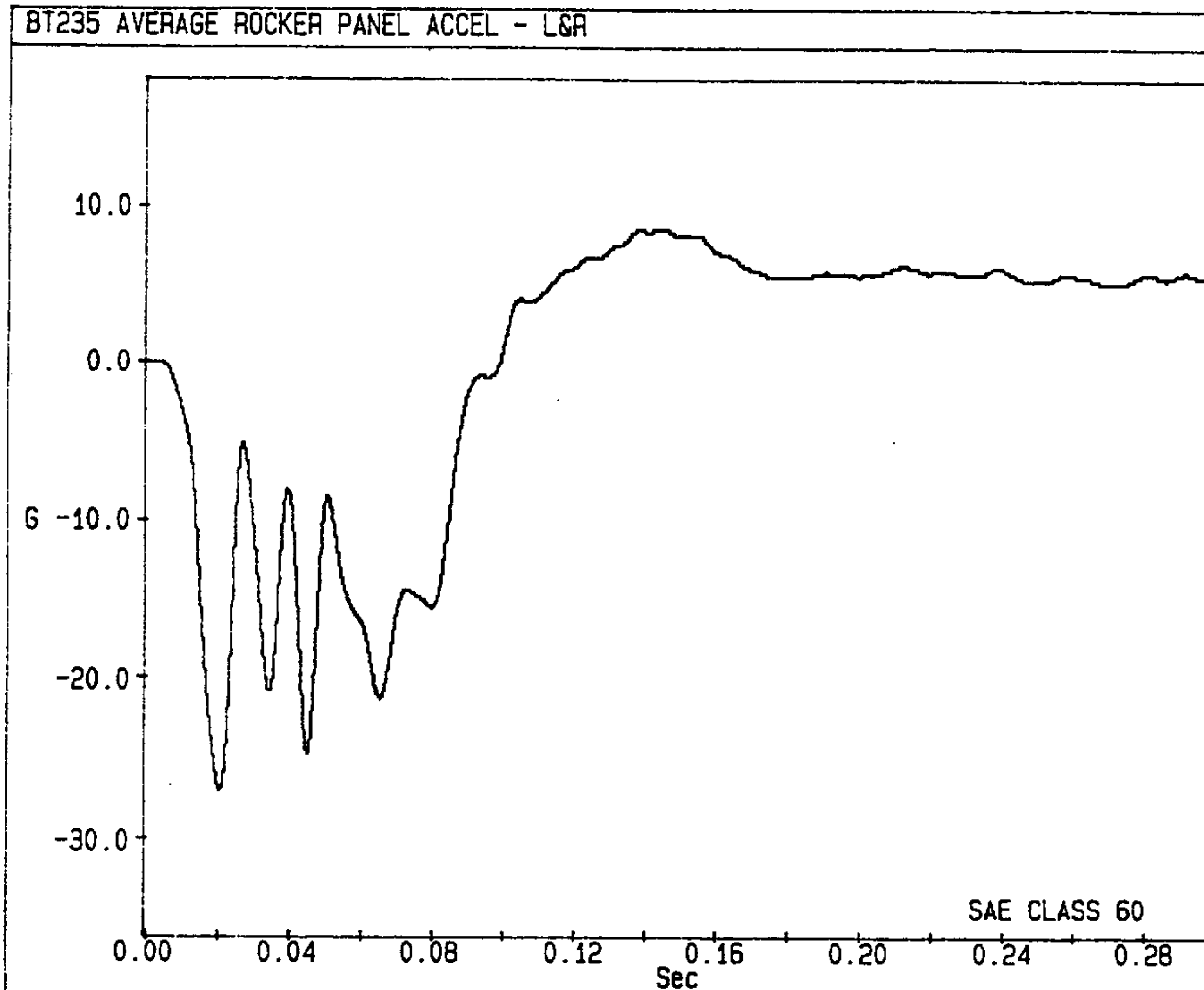
Appendix 5

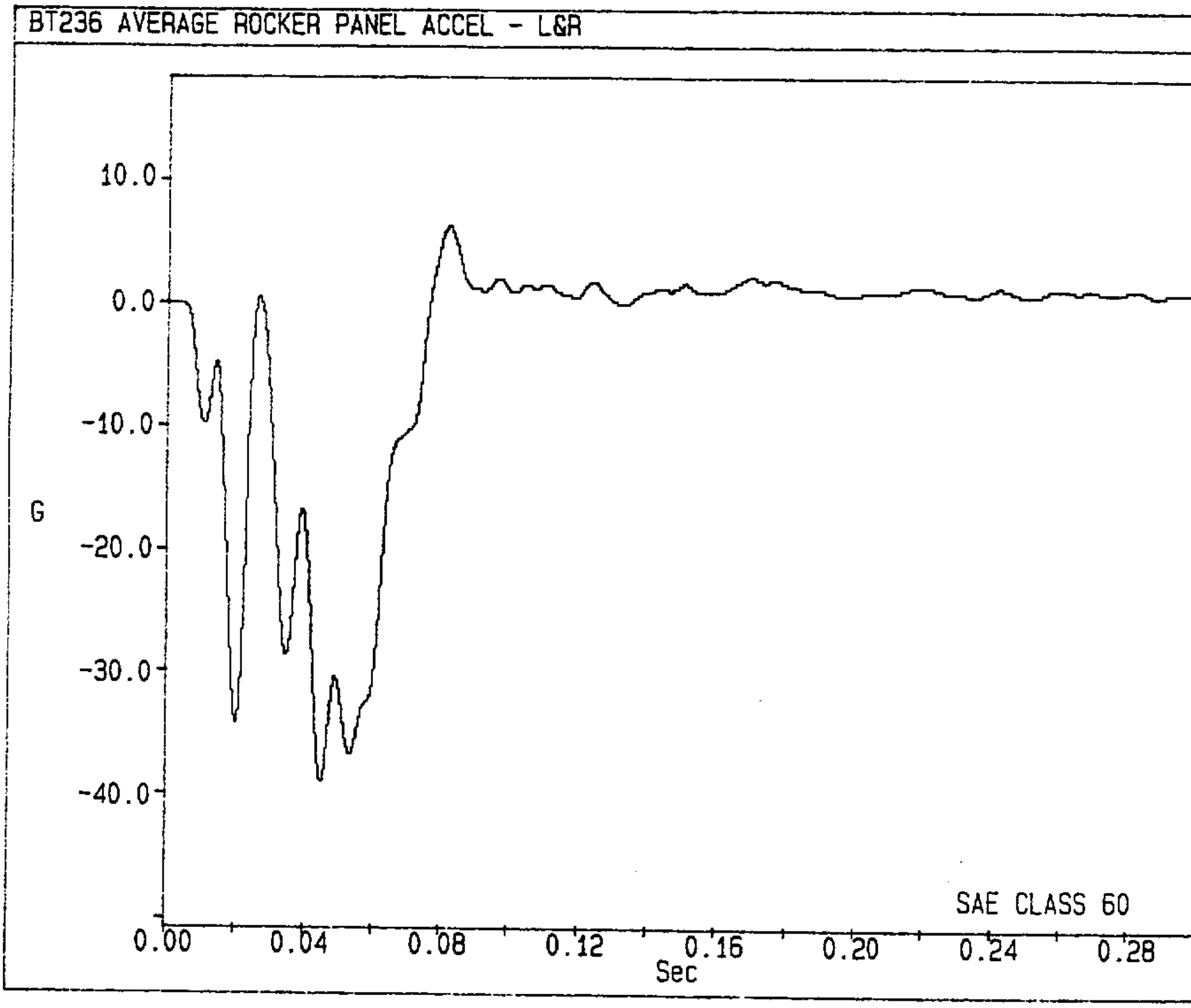
Phase 1 Test Vehicle Crash Pulses

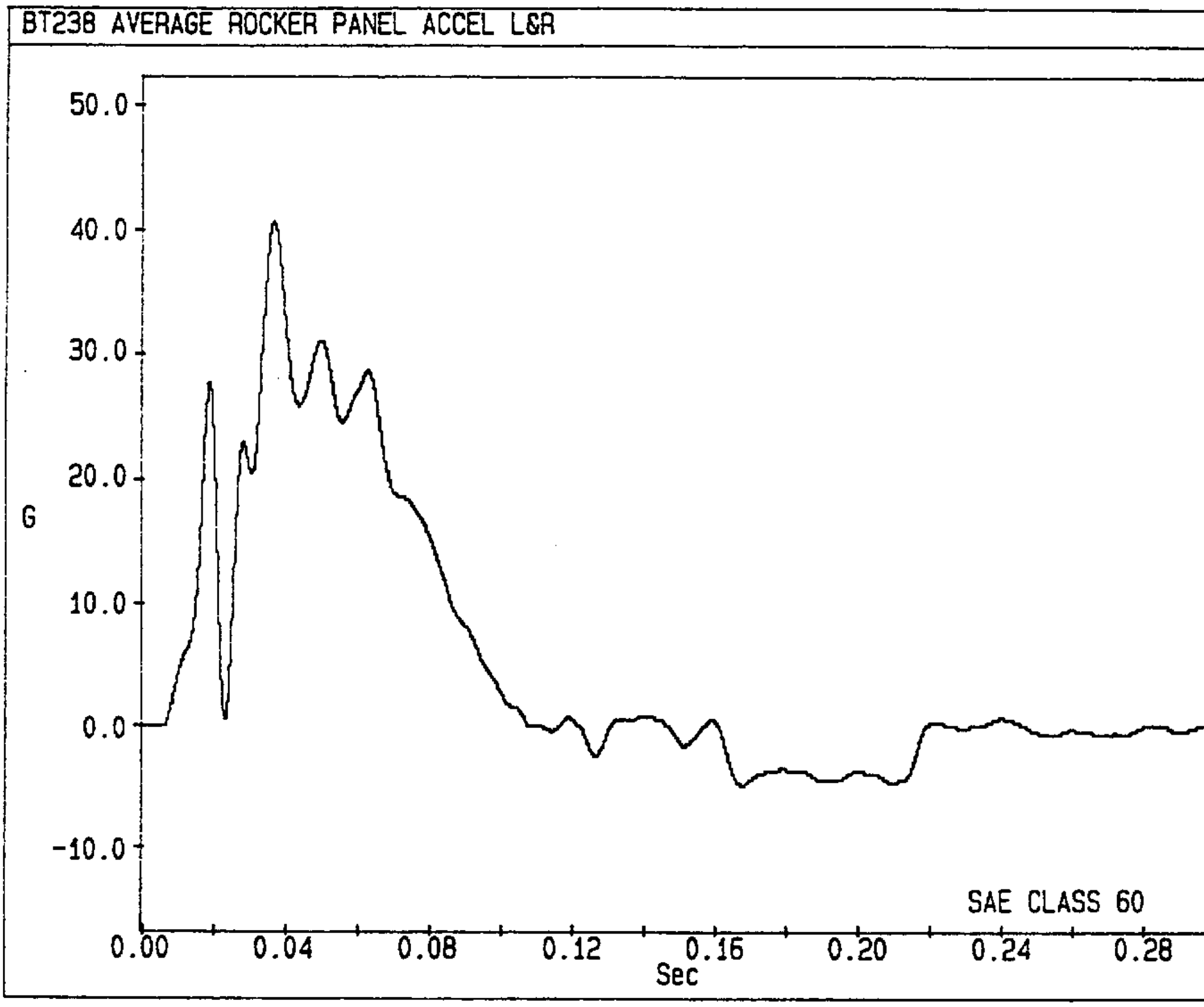

BT225 AVG ROCKER PANEL L&R ACCEL - SAE CLASS 60
20.0
0.0
G
-20.0
-40.0
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
Sec

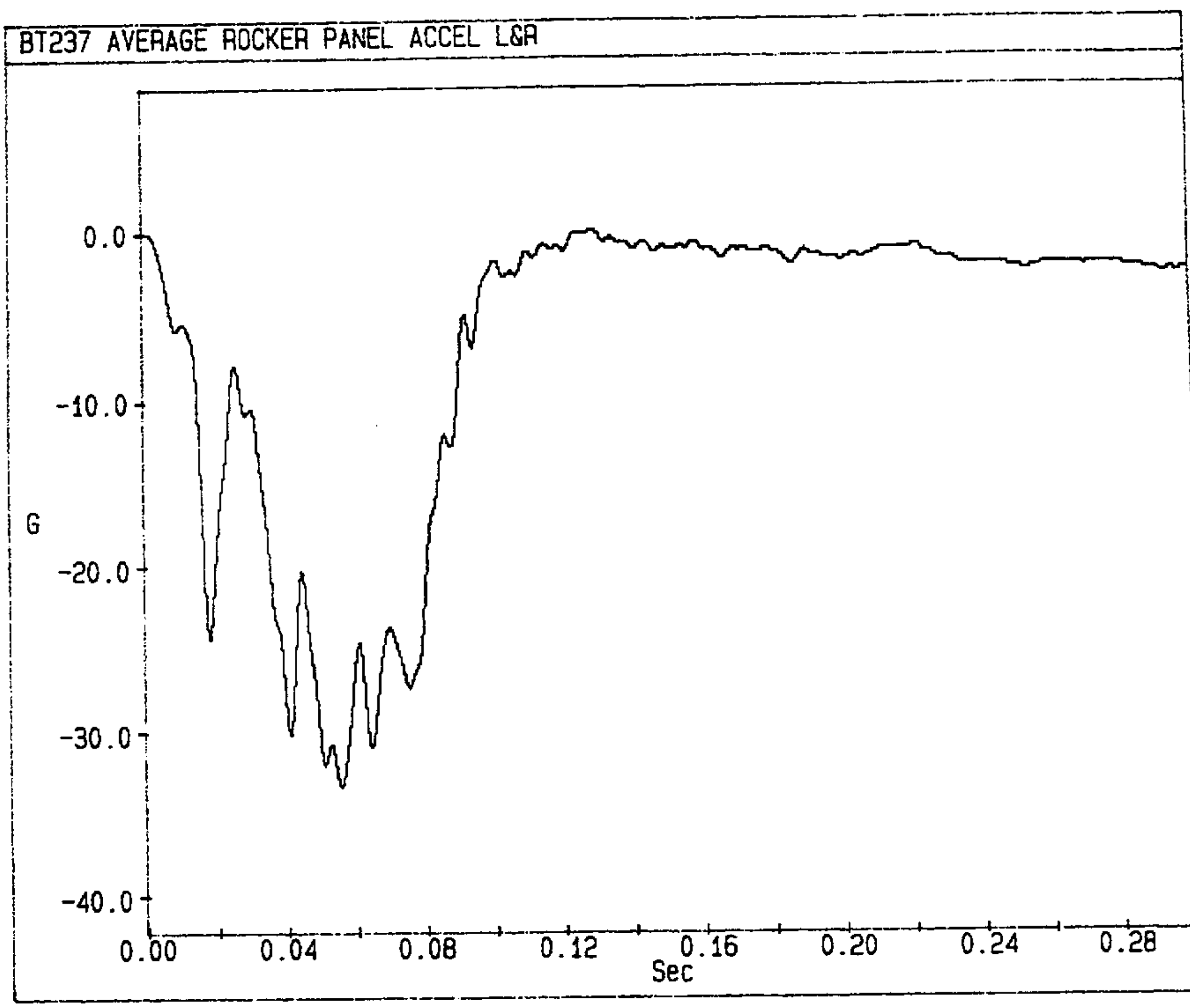

BT228 AVG ROCKER PANEL L&R ACCEL
10.0
0.0
-10.0
-20.0
-30.0
G
MAX Accel = 28.0 G at 61.5ms
SAE CLASS 60
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
Sec


BT234 AVERAGE ROCKER PANEL ACCEL L&R
10.0
0.0
-10.0
-20.0
-30.0
-40.0
G
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
Sec
SAE CLASS 60


BT235 AVERAGE ROCKER PANEL ACCEL - L&R
10.0
0.0
G -10.0
-20.0
-30.0
SAE CLASS 60
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
Sec

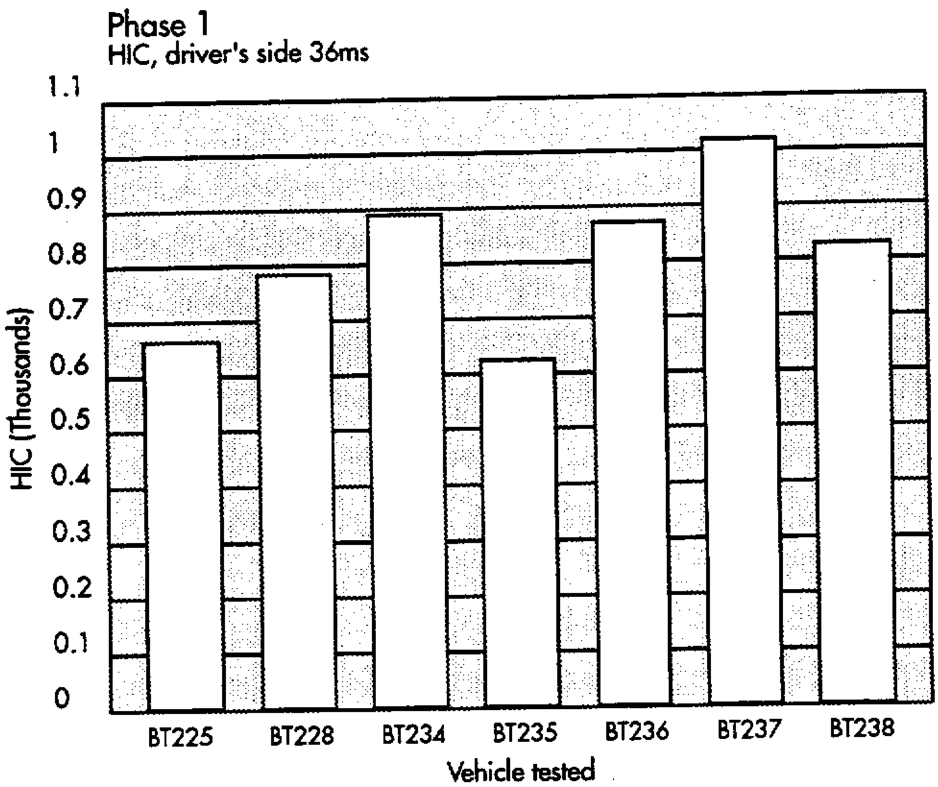

BT236 AVERAGE ROCKER PANEL ACCEL - L&R
10.0
0.0
-10.0
-20.0
-30.0
-40.0
G
SAE CLASS 60
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
Sec

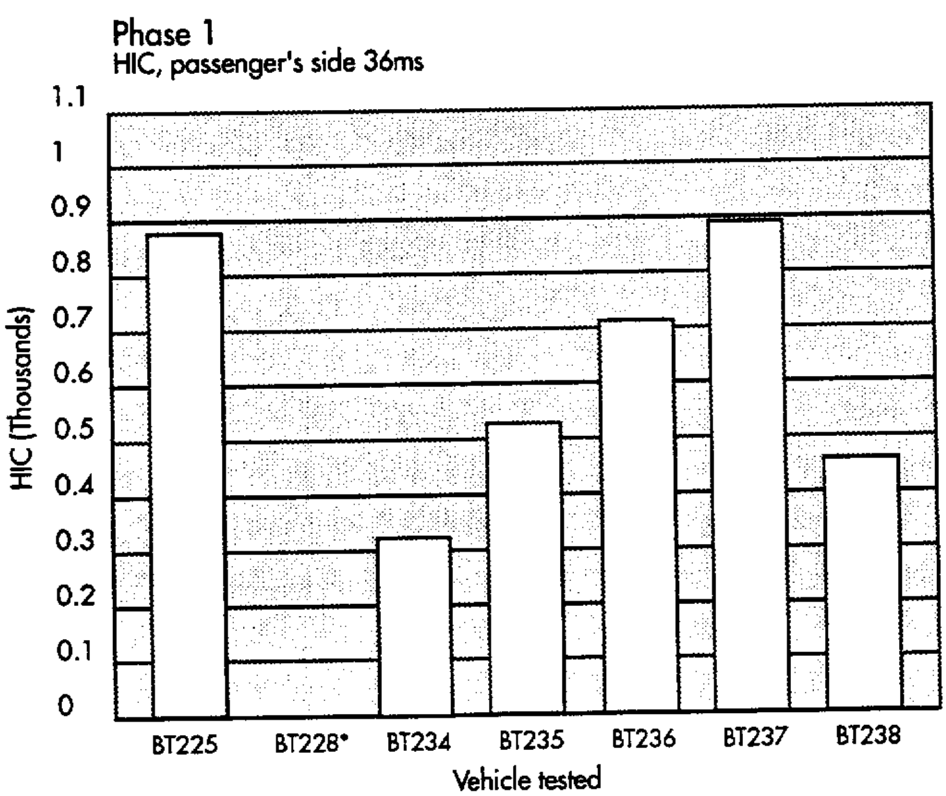

BT238 AVERAGE ROCKER PANEL ACCEL L&R
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
G
SAE CLASS 60
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
Sec


BT237 AVERAGE ROCKER PANEL ACCEL L&R
0.0
-10.0
-20.0
-30.0
-40.0
G
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
Sec

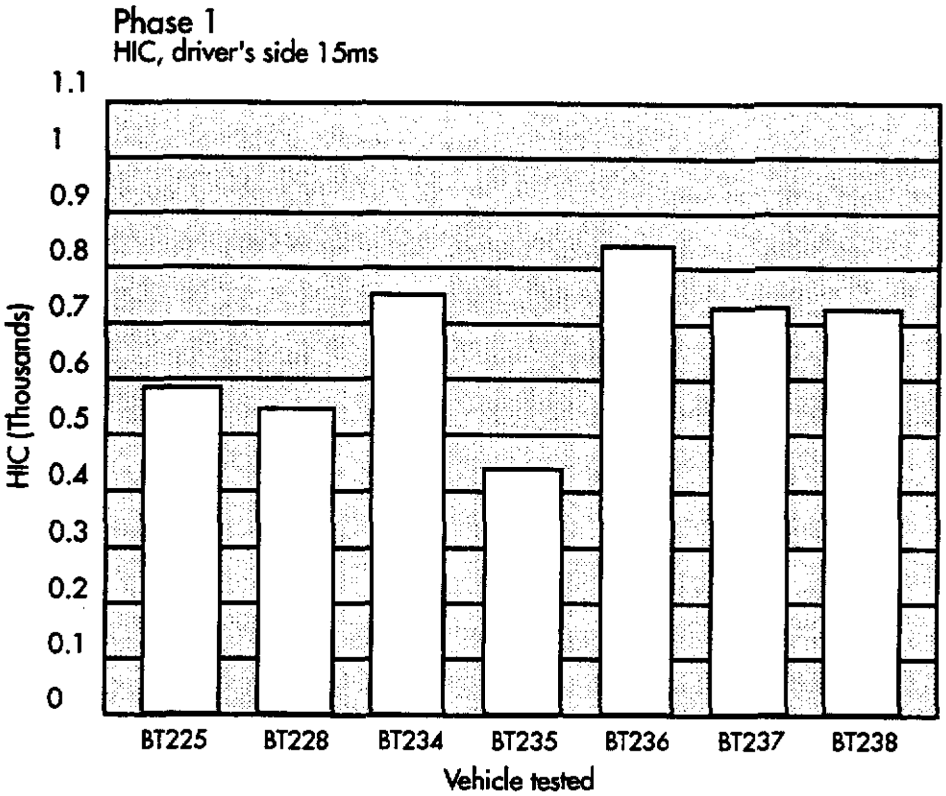
Appendix 6

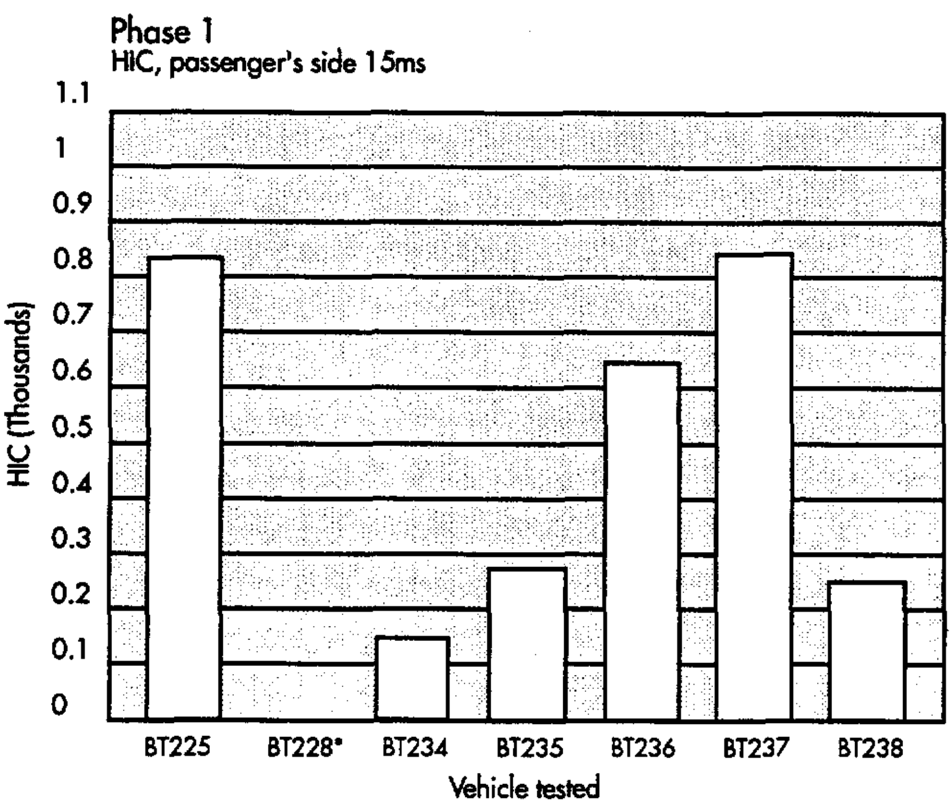
Phase 1 Bar Charts of Injury Criteria by Type





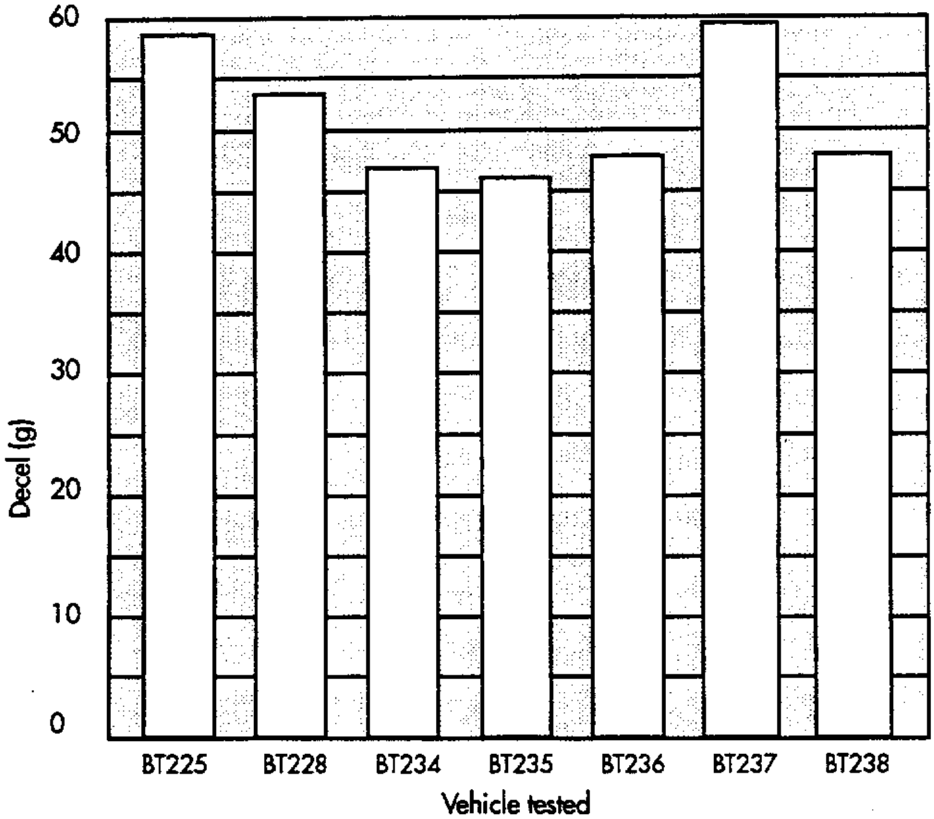
* Data lost due to equipment failure



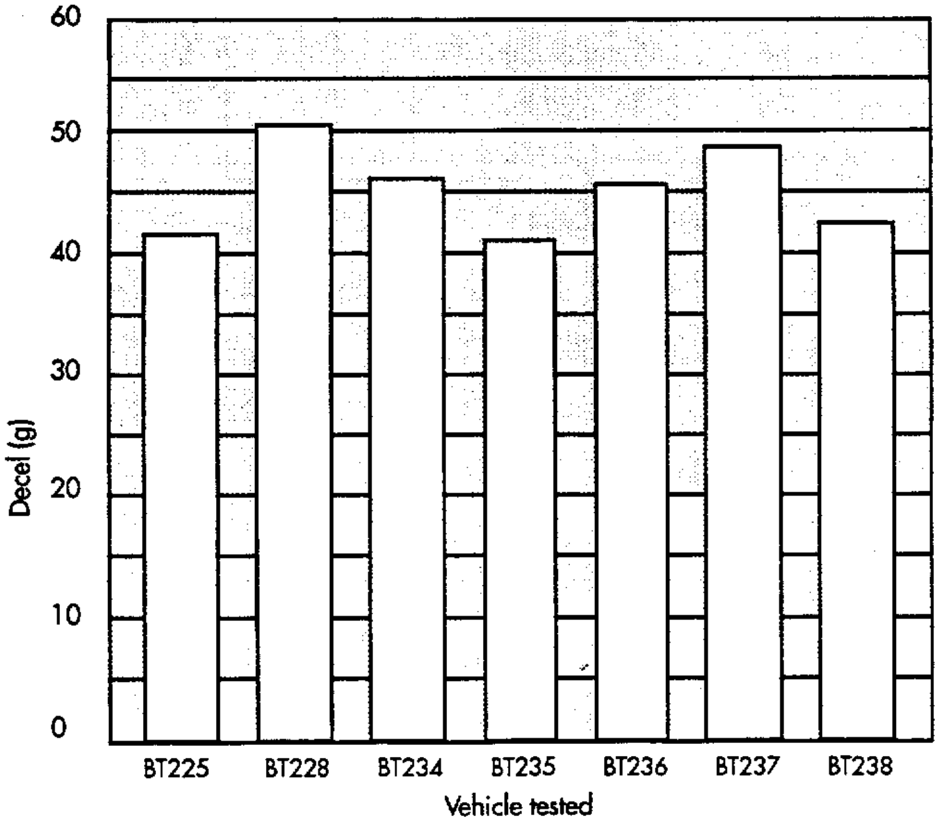


* Data lost due to equipment failure

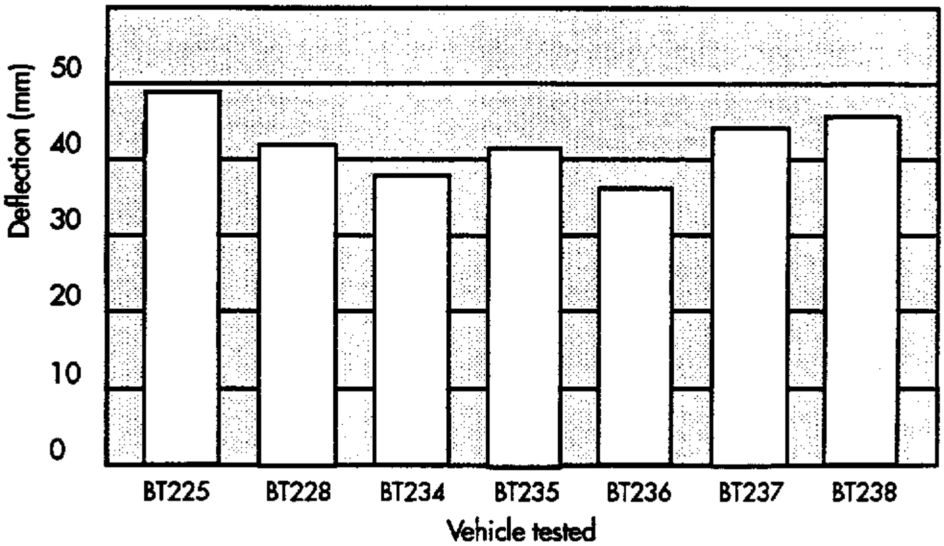
Phase 1
Chest decel (g) driver



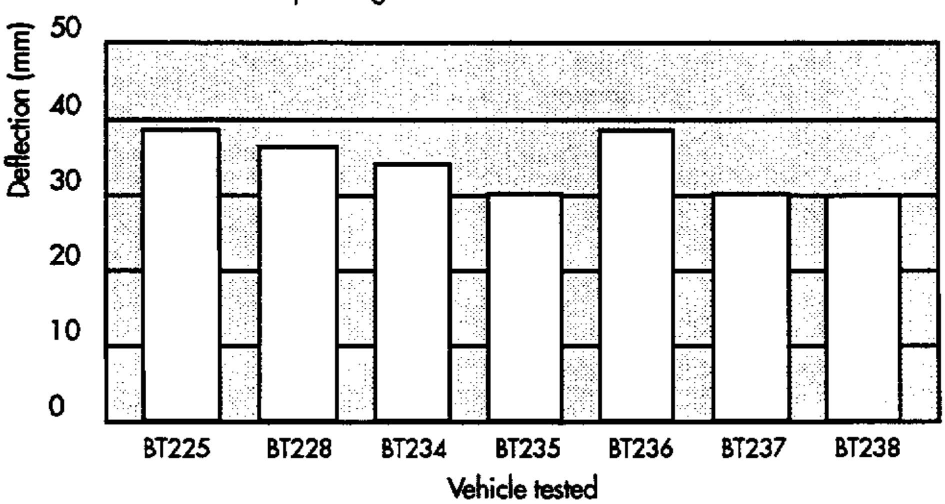
Phase 1
Chest decel (g) passenger

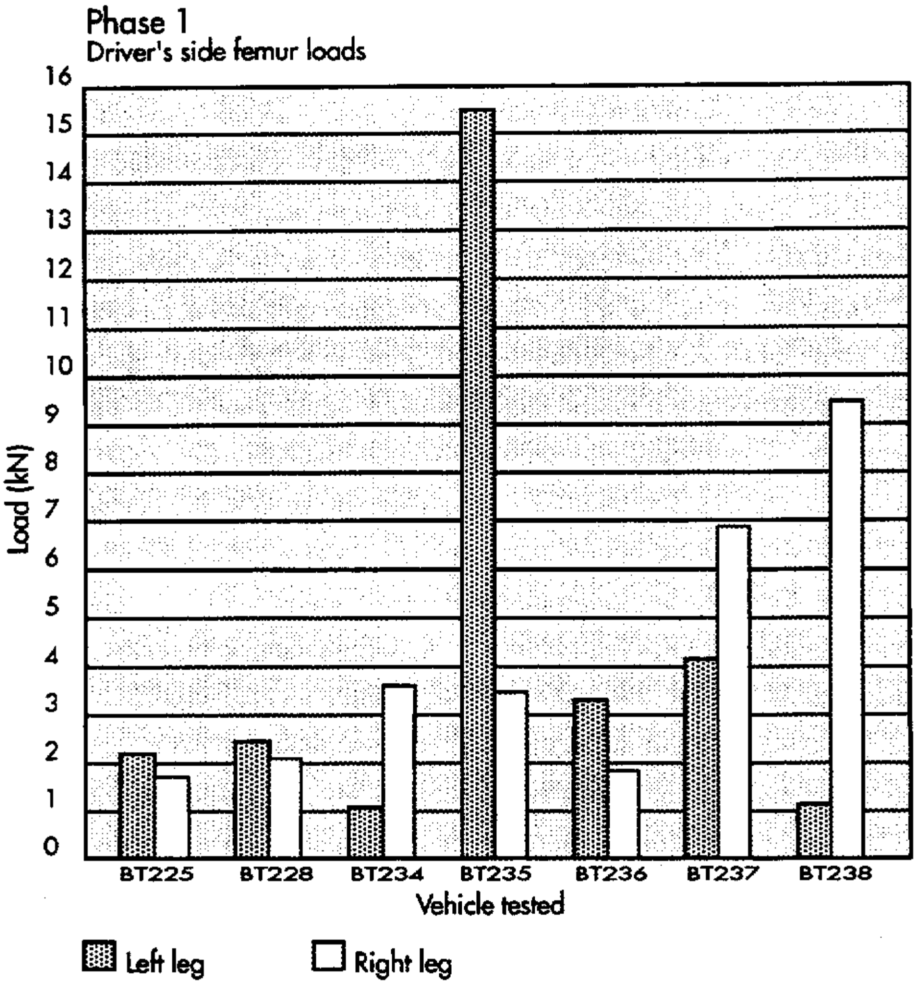


Phase 1
Chest deflection driver

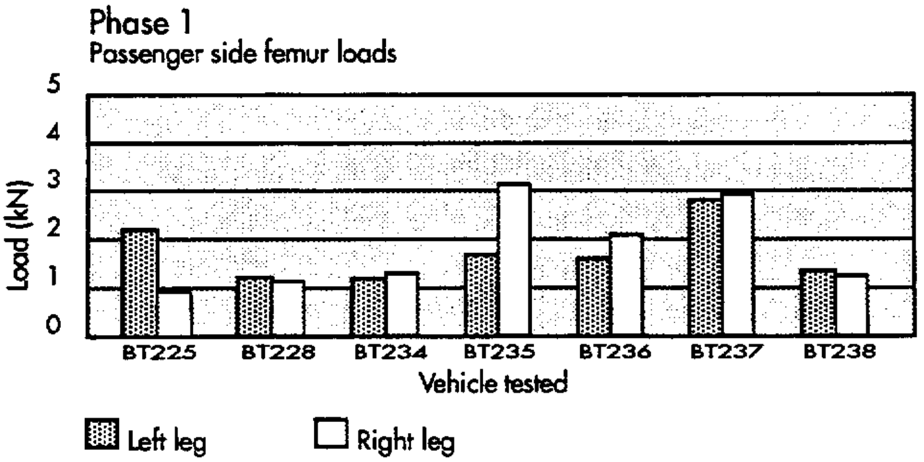


Phase 1
Chest deflection passenger





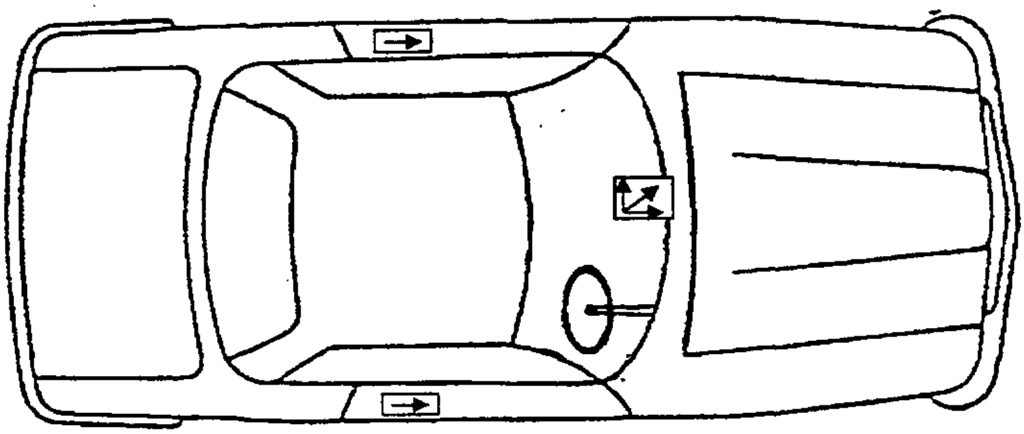
Phase 1
Driver's side femur loads
Load (kN)
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
BT225
BT228
BT234
BT235
BT236
BT237
BT238
Vehicle tested
Left leg
Right leg



Phase 1
Passenger side femur loads
Load (kN)
5
4
3
2
1
0
BT225
BT228
BT234
BT235
BT236
BT237
BT238
Vehicle tested
Left leg
Right leg

Appendix 7

Phase 2 General Test Set up and Dummy Positioning

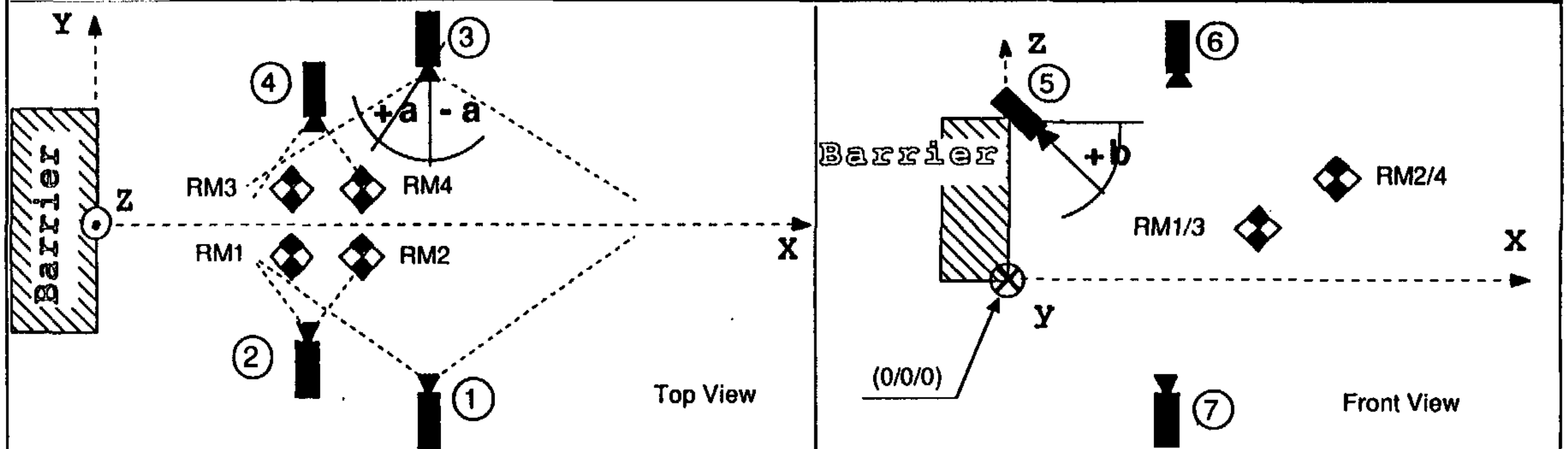


= 3 axial = 1 axial

Sensorposition	Measurement axis
Door sill B-pillar left	x - axis
Door sill B-pillar right	x - axis
Transmission tunnel	x, y, z - axis

Source: Autoliv Report on Sled Tests on Ford Laser — Evaluation of Modified Belt System, Energy Absorbing Steering Wheel andEurobag (10)

X00B0001 - 11 Camera Positions

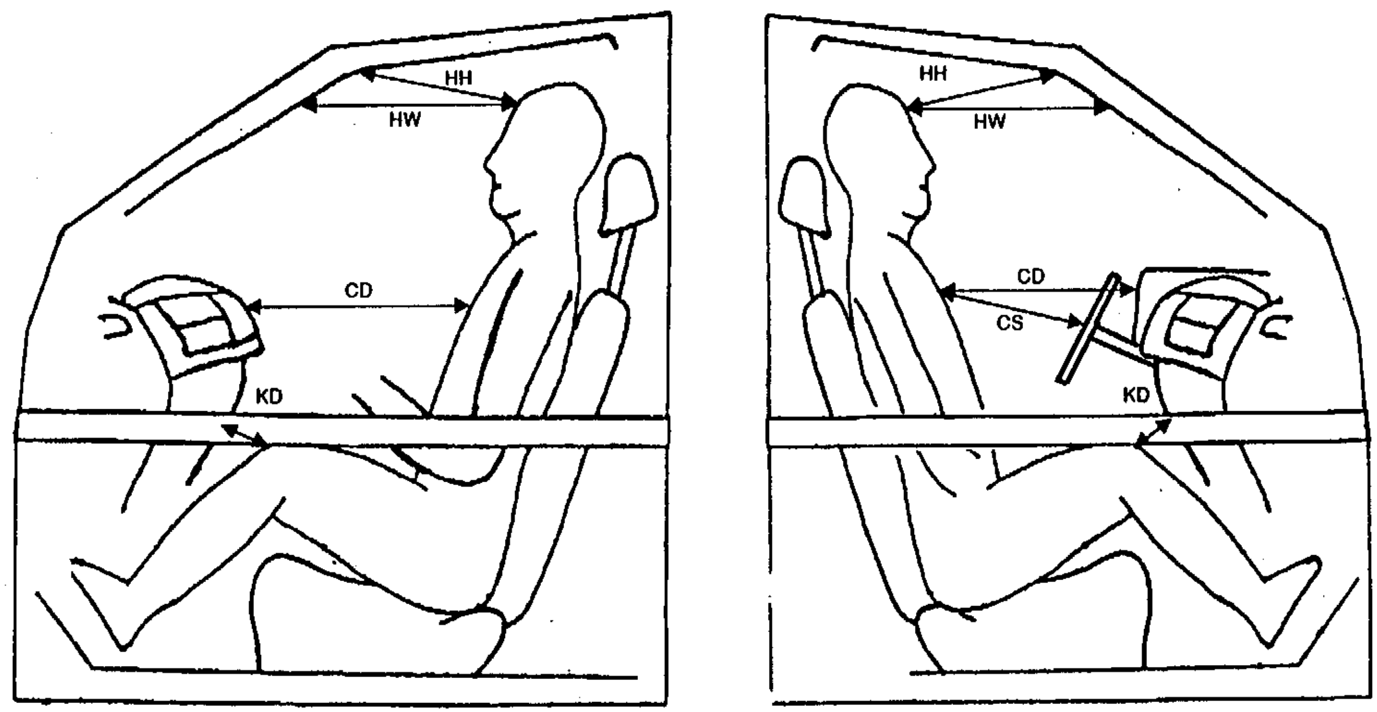


Camera	X [m]	Y [m]	Z [m]	a [°]	b [°]	Focus Length	Aper-ture	pps	Time Mar-ker/sec	Film	Light Value	Camera Type	Operat. Time
1													
2	3,7	-7,38	0,98										
3	3,5	7,38	1										
4	3,7	7,38	0,98										
5	0,3	0	1,74										
6													
7													

RM 1	x =3,0	y=-1,75	z=0,4	RM 3	x =3,0	y=1,75	z=0,4	RM : Room Marker
RM 2	x =4,0	y=-1,75	z=0,8	RM 4	x =4,0	y=1,75	z=0,8	WW: Wide Angle lenses

Electrolux Autoliv

X00B0001 - 11 DUMMY LOCATION MEASUREMENTS



Electrolux Autoliv

Dummy Location Measurements

Testnumber	HR [mm]	HW [mm]	CD [mm]	CS [mm]	KD l. [mm]	KD r. [mm]	NR [mm]	NH [mm]	V [mm]	H [mm]	SEAT BACK ANGLE
Passenger											
Crash	295	428	493	N/A	120	129	N/A	N/A	158	153	25°
X00B0001	305	---	475	---	105	105	---	---	162	145	25°
X00B0002	305	---	490	---	125	125	---	---	160	145	25°
X00B0004	310	---	475	---	100	95	---	---	155	145	25°
X00B0006	295	---	475	---	100	90	---	---	170	175	25°
X00B0007	290	---	495	---	110	110	---	---	165	150	25°
Driver											
Driver	318	450	497	315	146	121	382	418	155	143	25°
X00B0003	305	--	490	310	125	125	470	380	160	145	25°
X00B0005	330	---	---	300	90	80	475	375	165	160	25°
X00B0008	315	---	---	315	100	80	490	410	170	170	25°
X00B0009	310	---	---	300	100	80	460	400	165	165	25°
X00B0010	310	---	---	320	100	80	470	400	170	165	25°
X00B0011	290	---	---	300	90	90	475	365	145	165	25°

HH Head to windscreen header
HW Head to windscreen (horizontal)
CD Chest to dash
CS Chest to steering wheel
KD Knees to dash
HR Head to side header

AD Arm to trim
HD Hip to door
NR Distance from tip of dummy's nose to top rear surface of steering wheel rim
NH Distance from tip of dummy's nose to center of steering column hub

Appendix 8

Phase 3 Test Vehicle Photographs

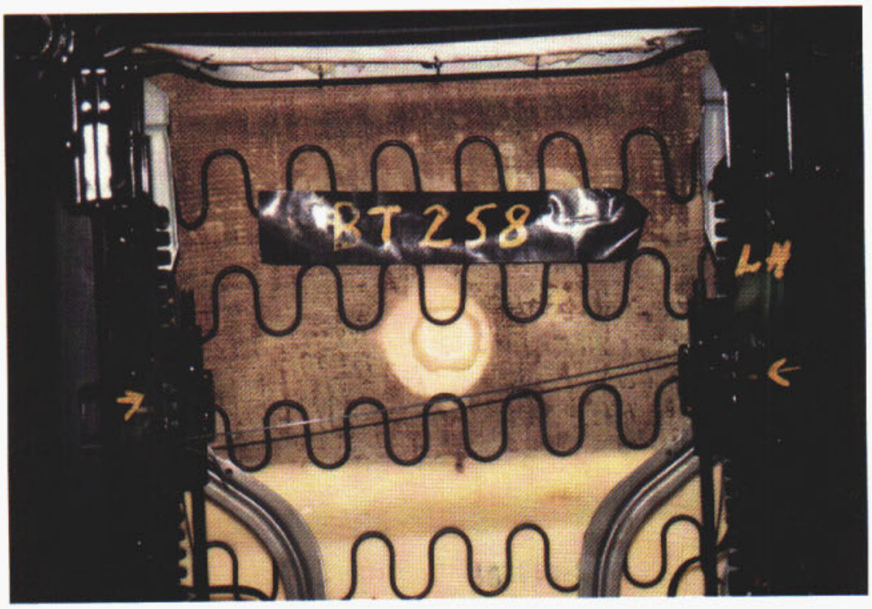
Appendix 8

This appendix contains photographs of each test vehicle depicting:

- post-test side and overhead views
- pre-test and post-test views of the driver and passenger Hybrid III dummies
- components of the enhanced restraint systems used
- dummy contact points with vehicle interior where applicable.

It also contains photographs of a typical vehicle set-up for data acquisition, brake abort system and speed measuring device.

Modifications to seat adjusters and seat mountings which were carried out on all Phase 3 test vehicles. Seat adjusters welded in test position (mid-point of travel).



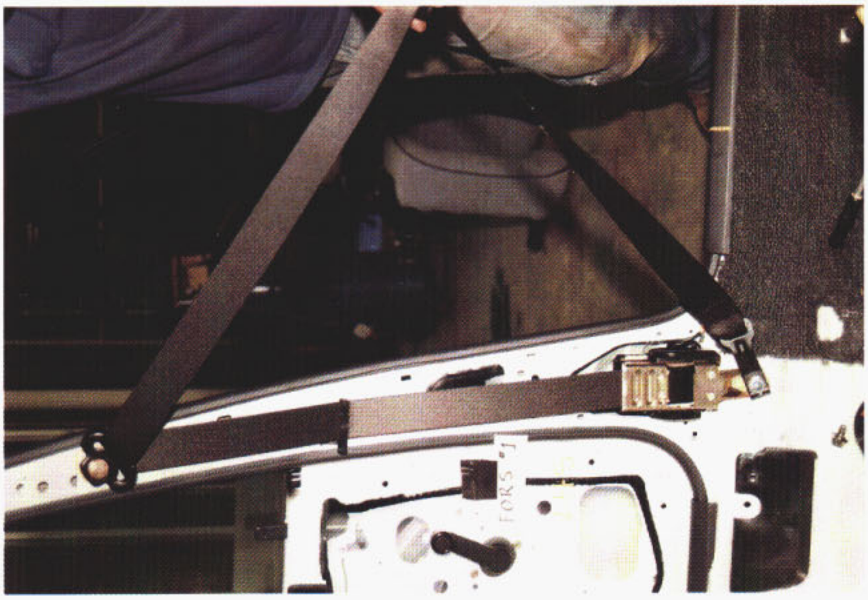
Reinforcement of inner rear seat mount. Right hand side shown, left hand identical.

BT252 — vehicle fitted with webbing clamp retractors and low elongation (7%) webbing, seat belt buckle pretensioners, and 'TRRL' energy absorbing steering wheel. Overhead view.

BT252 — driver's side view

BT252 — passenger's side view

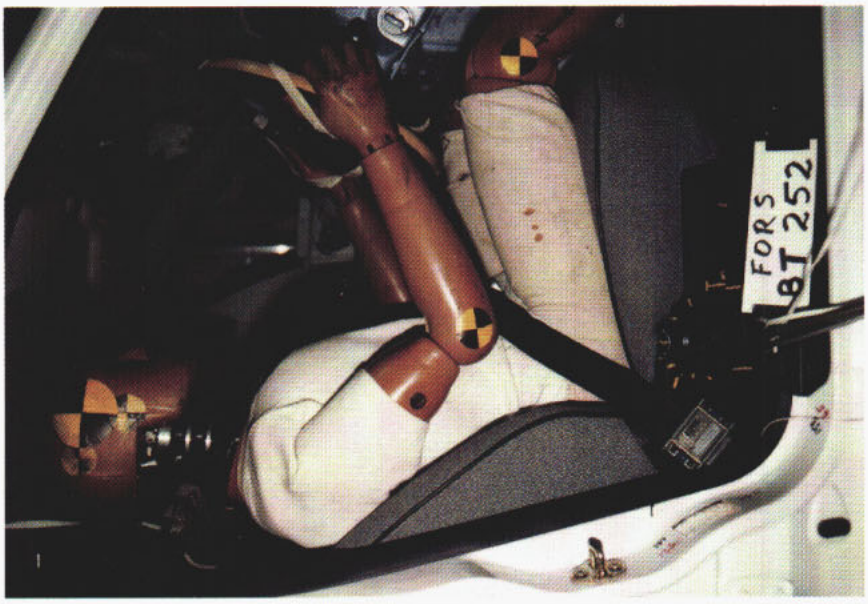
BT252 — lap sash seat belt webbing clamp retractor with low elongation (7%) webbing. Middle position on B-pillar used as upper torso anchorage. Left hand side shown, right hand installation identical.



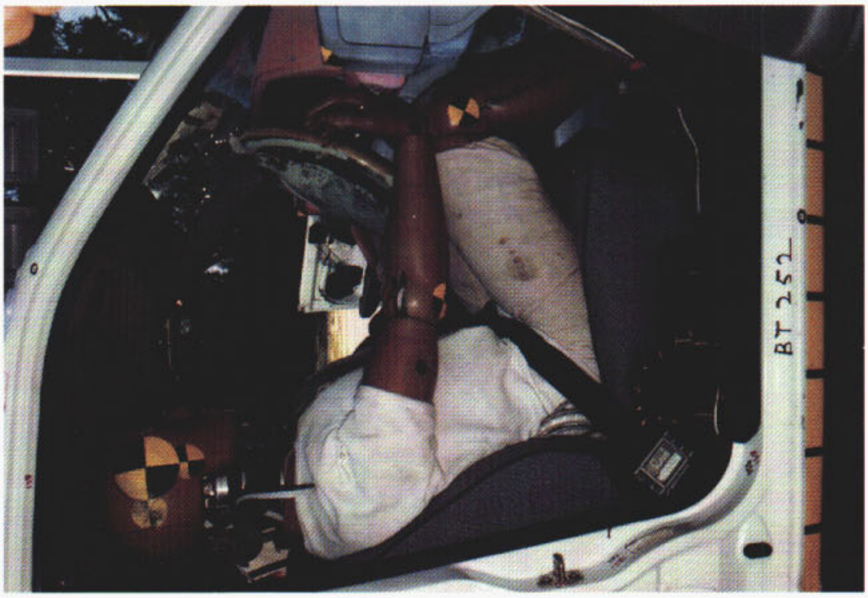
BT252 — seat belt buckle pretensioner mounted on inner seat adjuster. Wire from pretensioner is for measuring trigger time. Left hand side shown, right hand installation identical.

BT252 — energy absorbing steering wheel meeting test requirements developed by UK Transport Road Research Laboratory.

BT252 — pre-test driver's side

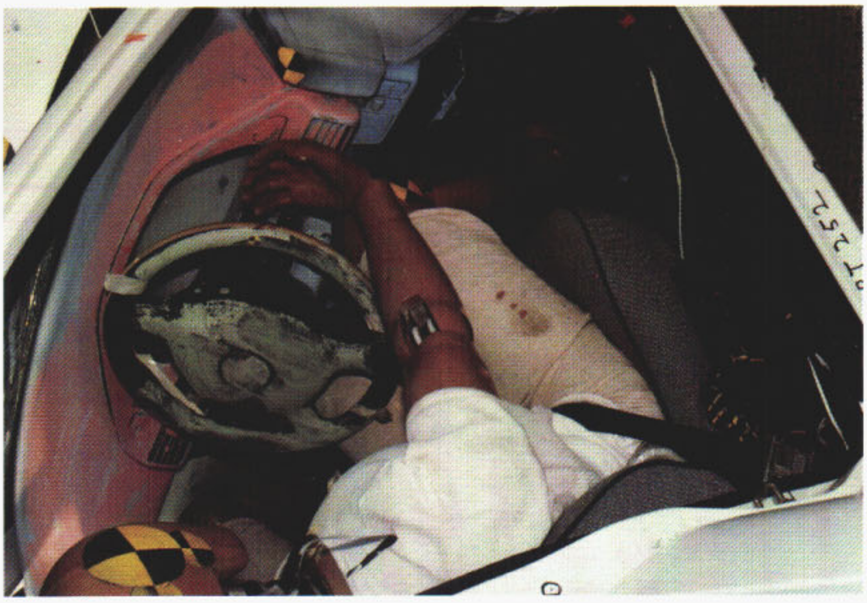


BT252 — post-test driver's side

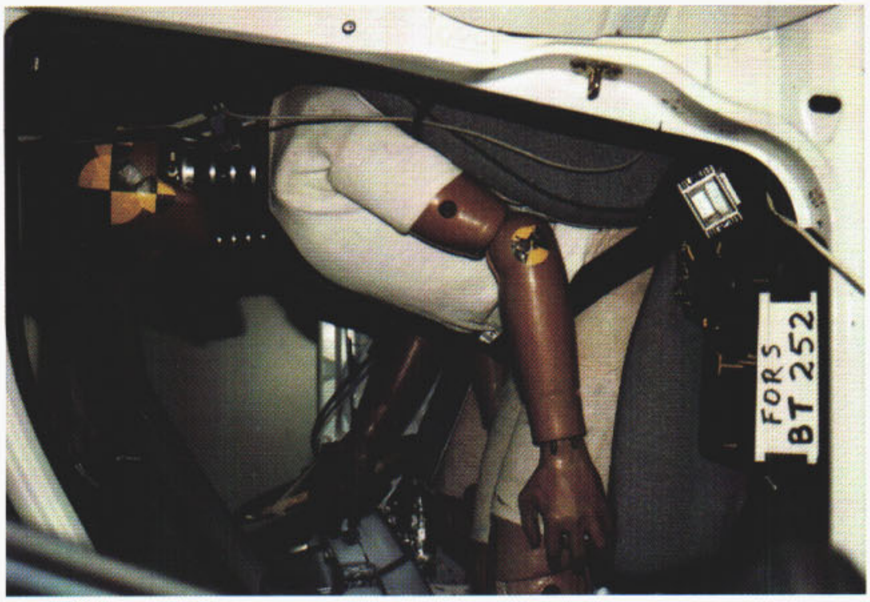


BT252 — driver's side impact zone

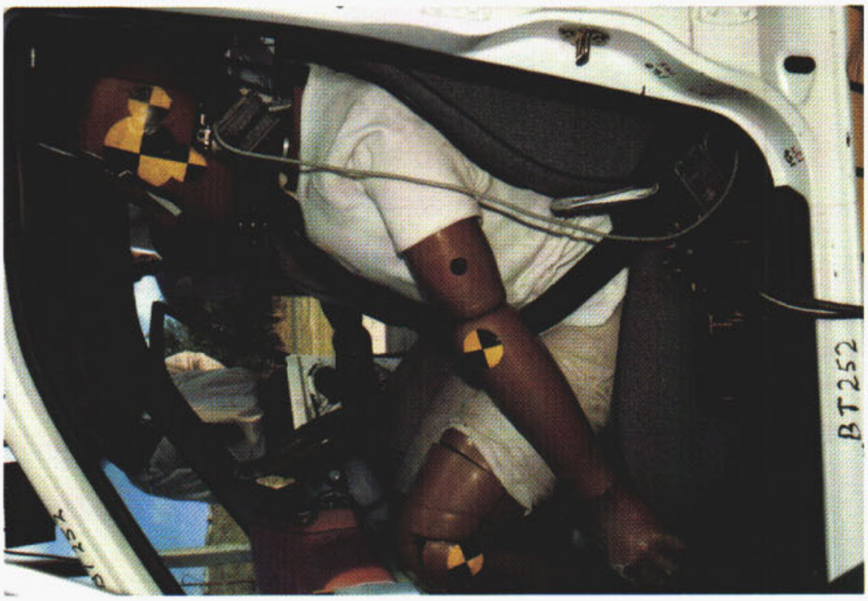
BT252 — driver's side impact zone



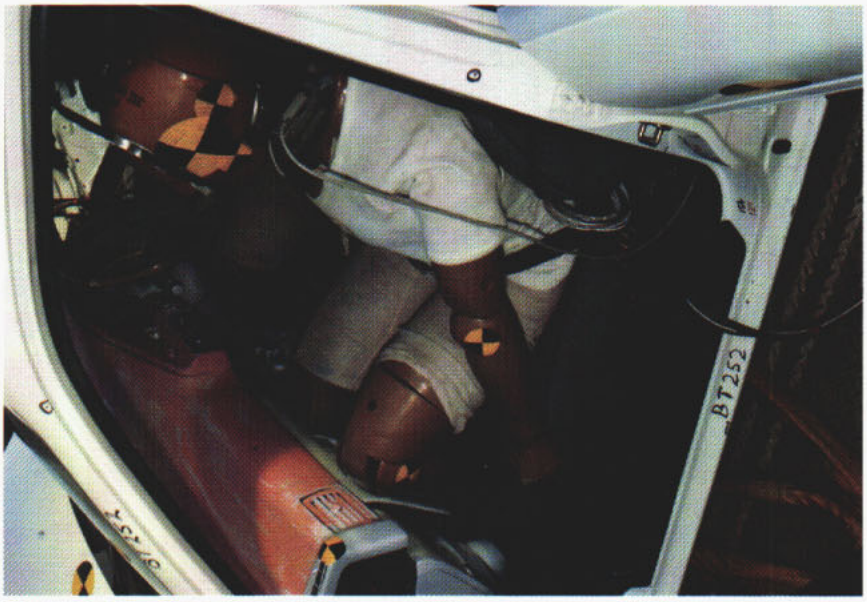
BT252 — pre-test passenger's side



BT252 — post-test passenger's side

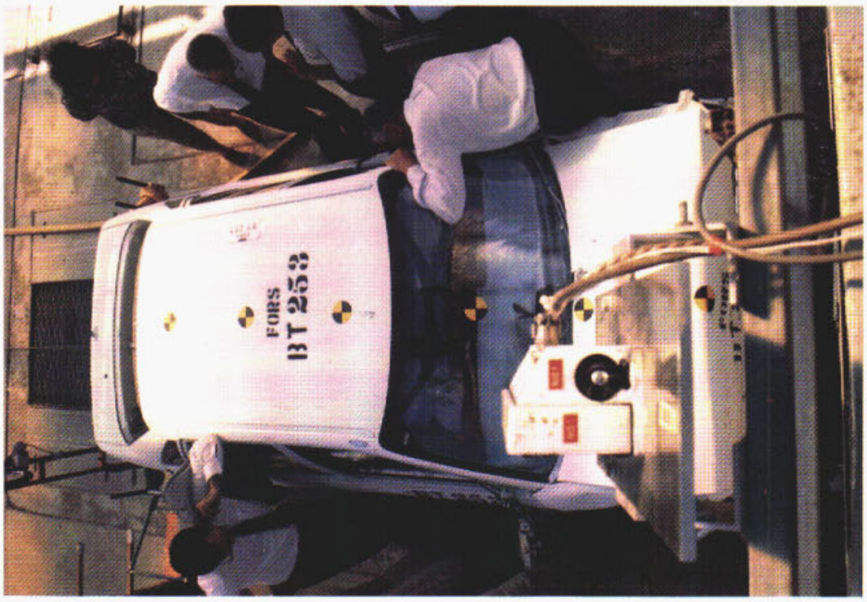


BT252 — passenger's side impact zone



BT252 — passenger's side impact zone. Note that there was no head contact with instrument panel.

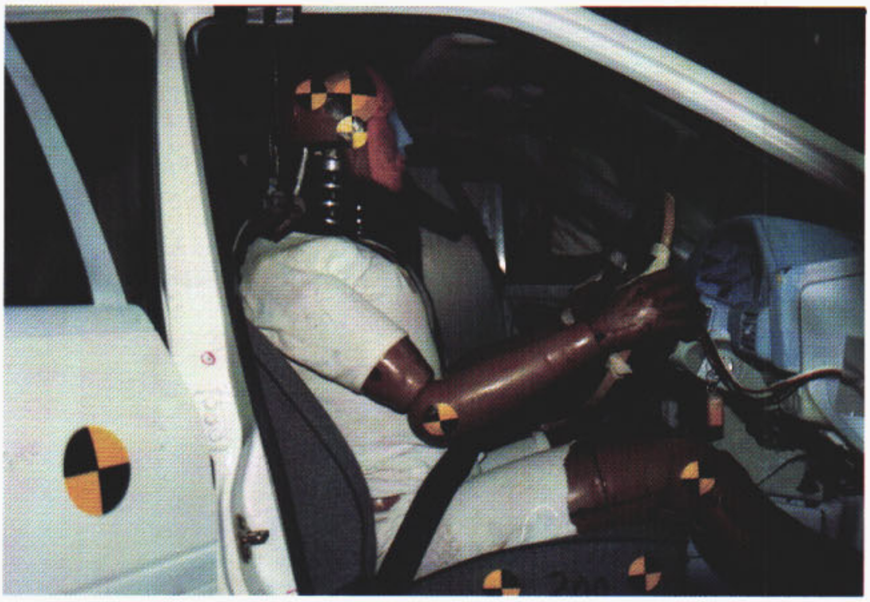
BT253 — vehicle fitted with standard (original equipment) seat belt system and driver's side facebag. Overhead view.



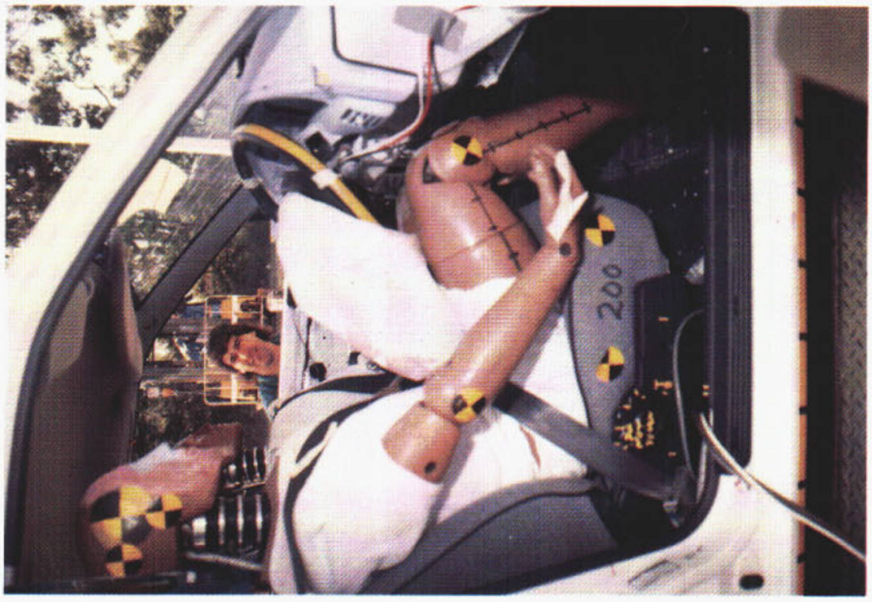
BT253 — driver's side view

BT253 — passenger's side view

BT253 — pre-test driver's side



BT253 — post-test driver's side



BT253 — driver's side impact zone

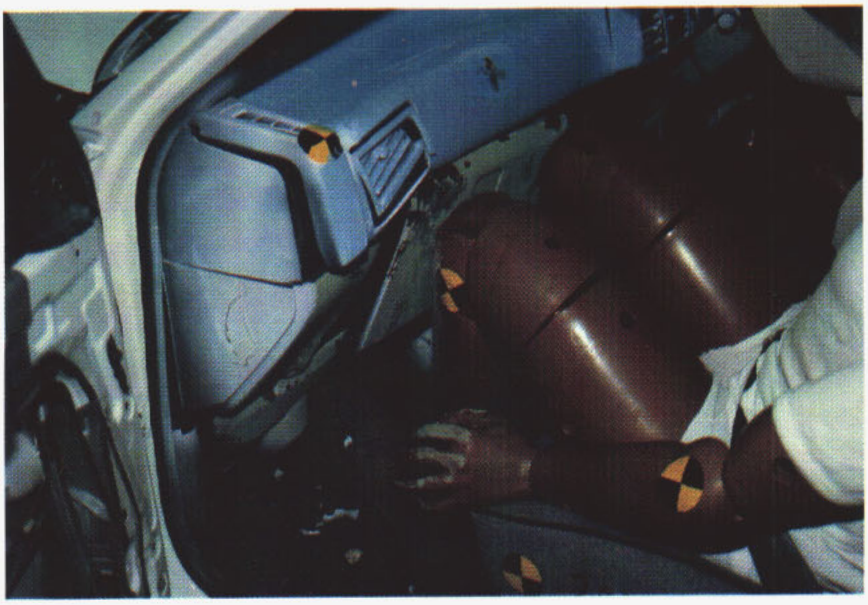
BT253 — driver's side impact zone. Markings on air bag and head give an indication of load distribution.

BT253 — pre-test passenger's side

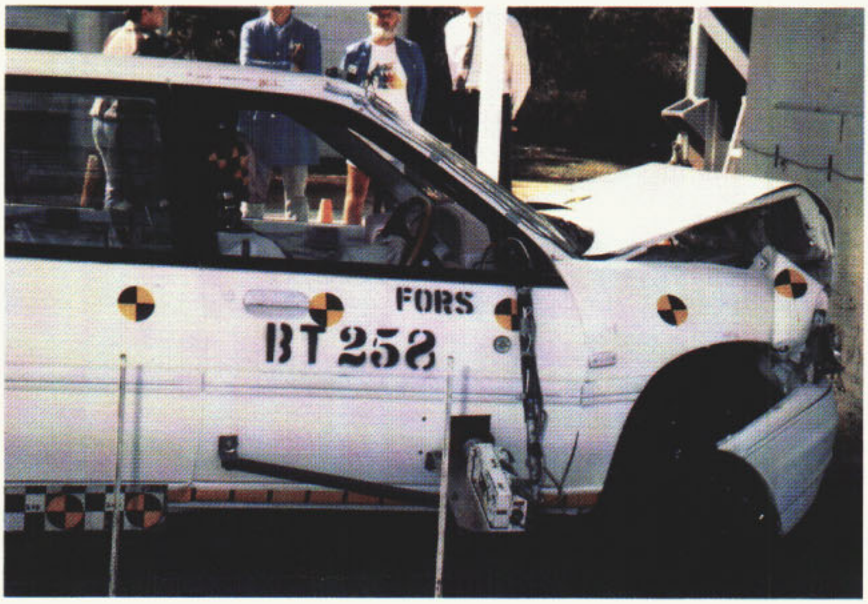
BT253 — post-test passenger's side

BT253 — passenger's side head impact zone

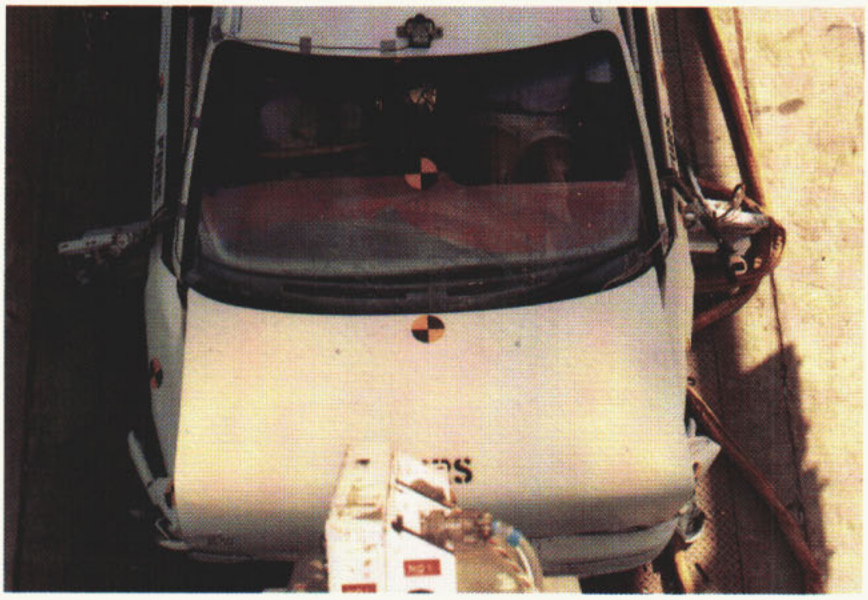
BT253 — passenger's side knee impact zone



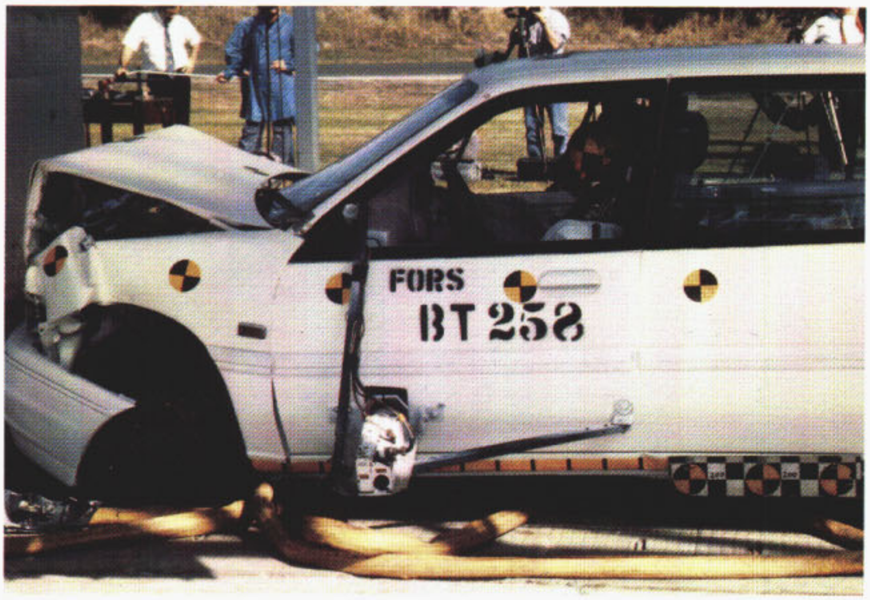
BT258 — driver's side view



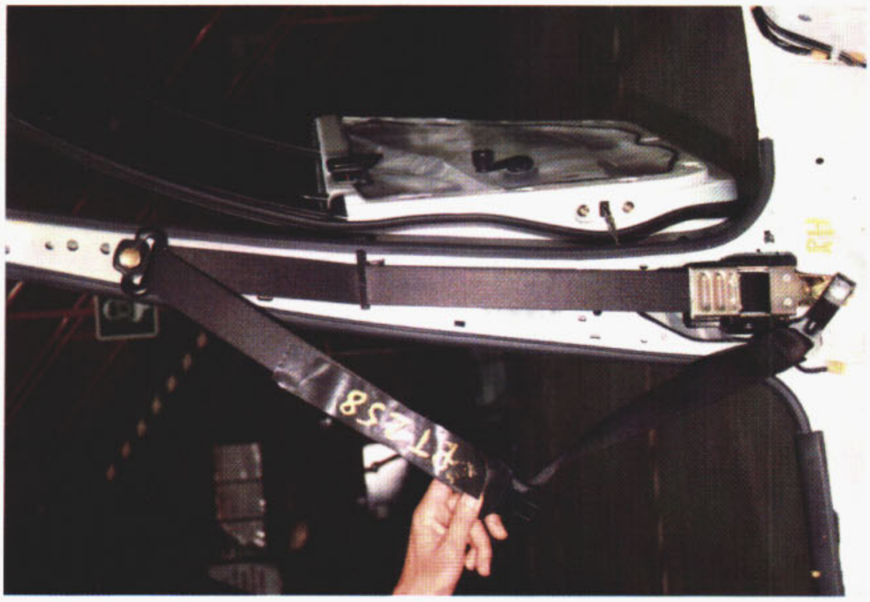
BT258 — vehicle fitted with seat belt webbing clamp retractors with low elongation (7%) webbing, seat belt buckle pretensioners and driver's side facebag. Overhead view.



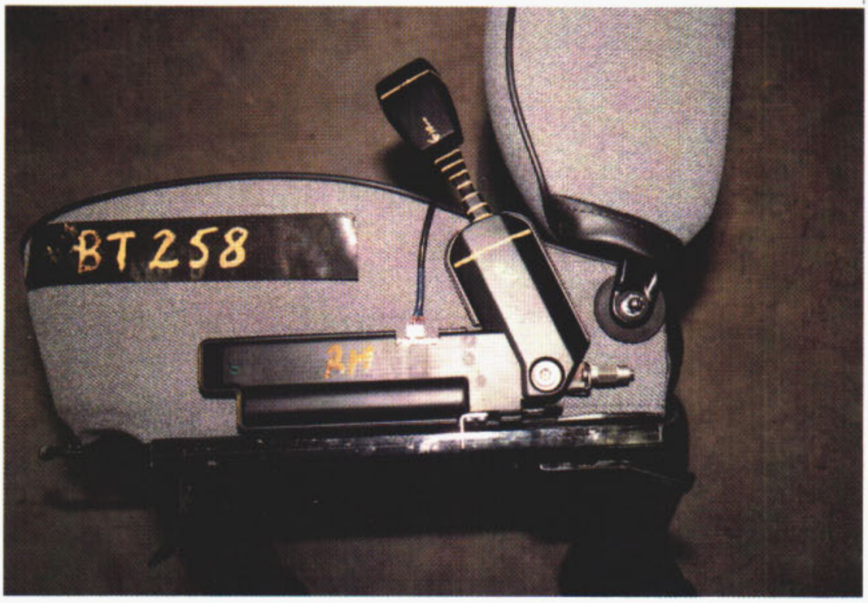
BT258 — passenger's side view



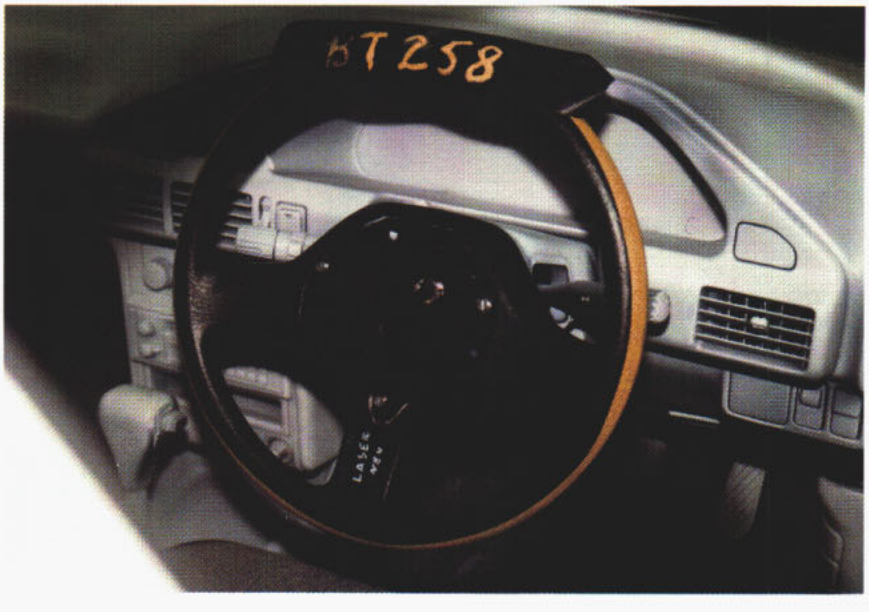
BT258 — lap sash seat belt webbing clamp retractor with low elongation (7%) webbing. Middle position on B-pillar used on driver's side as upper torso anchorage. Right hand side shown, left hand installation identical except upper position on B-pillar used on passenger's side as upper torso anchorage.



BT258 — seat belt buckle pretensioner mounted on inner seat adjuster. Wire from pretensioner is for measuring trigger time. Right hand side shown, left hand installation identical.



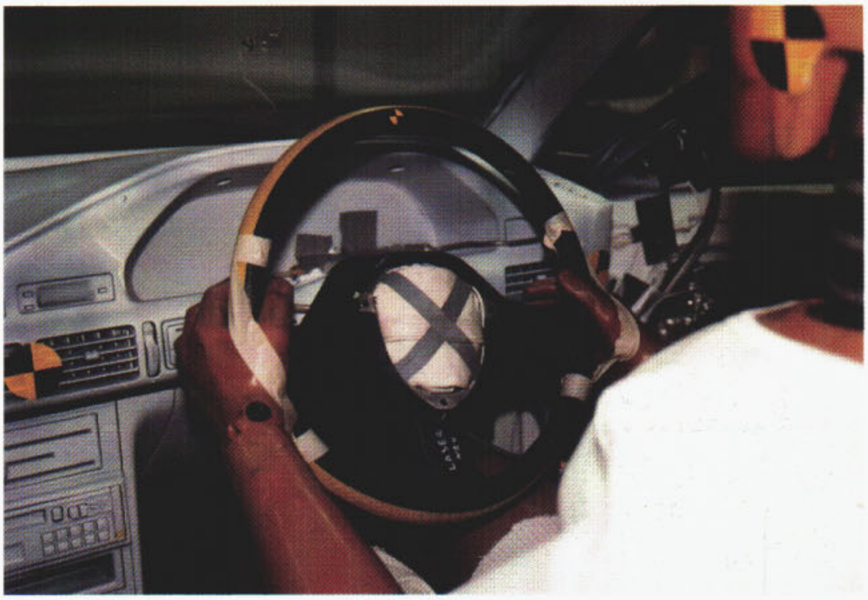
BT258 — original equipment steering wheel modified to accommodate facebag module. Same type of steering wheel used in BT253.



BT258 — pre-test driver's side

BT258 — post-test driver's side

BT258 — steering wheel with facebag module installed.

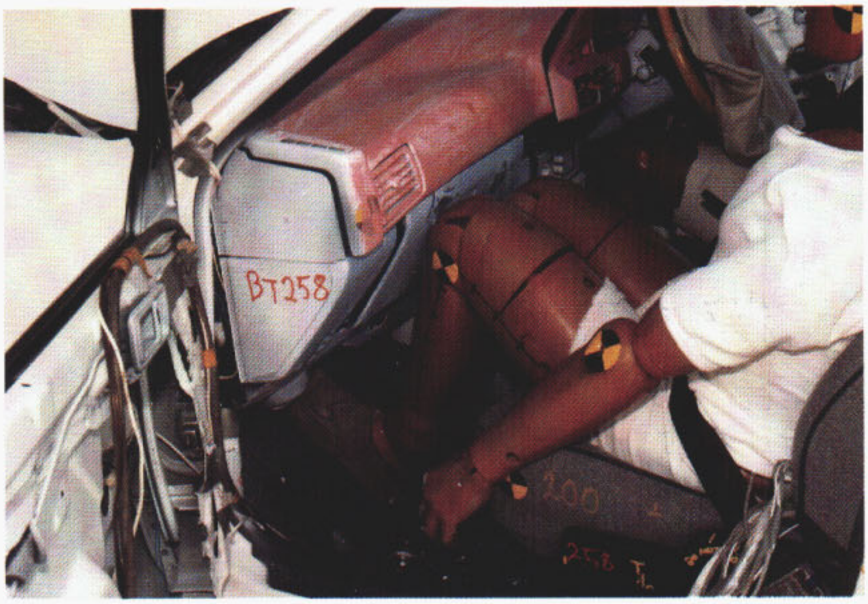


BT258 — driver's side head contact with facebag.

BT258 — pre-test passenger's side

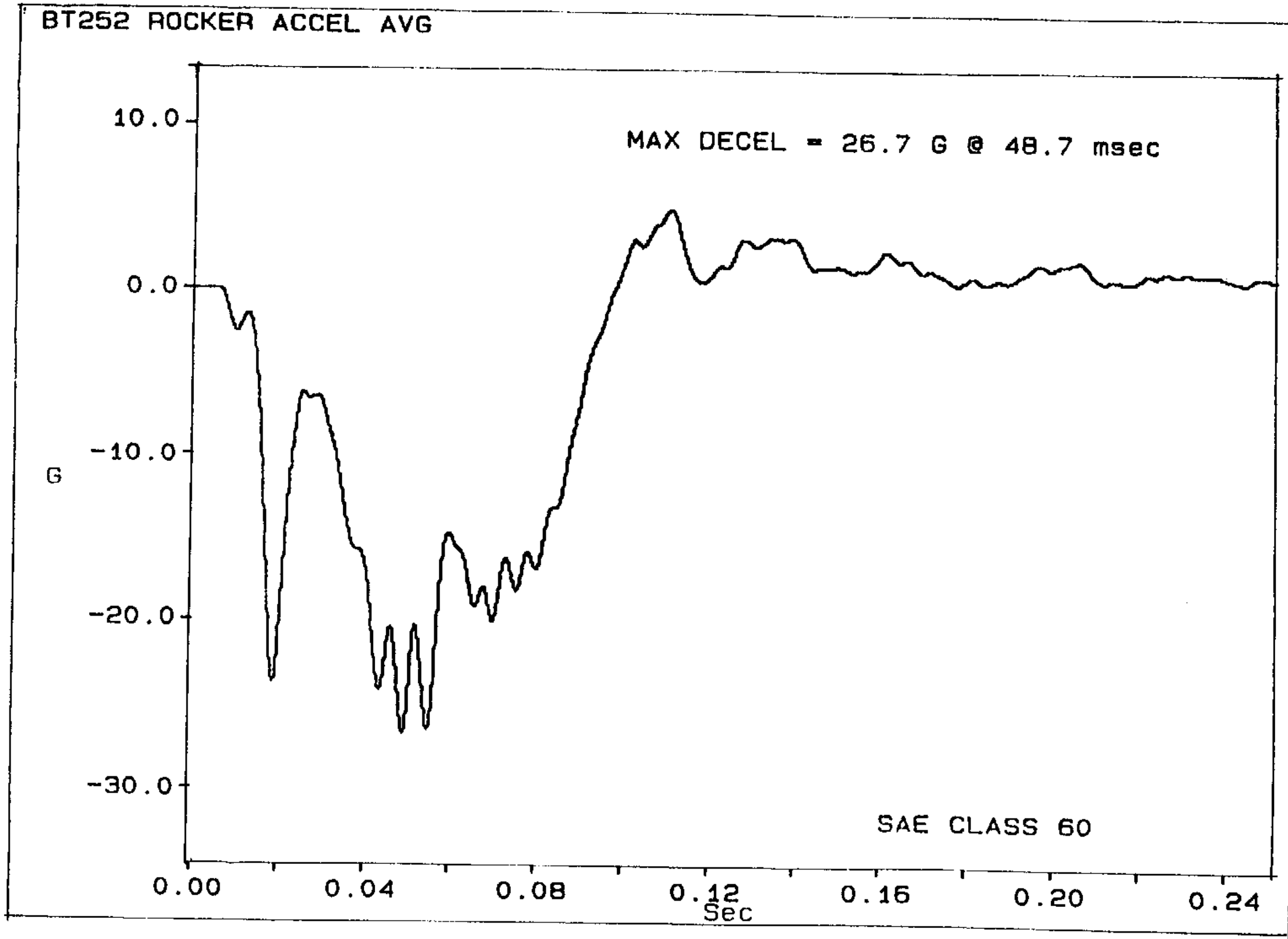
BT258 — post-test passenger's side

BT258 — passenger's side knee contact. Note there was no head contact with the instrument panel.

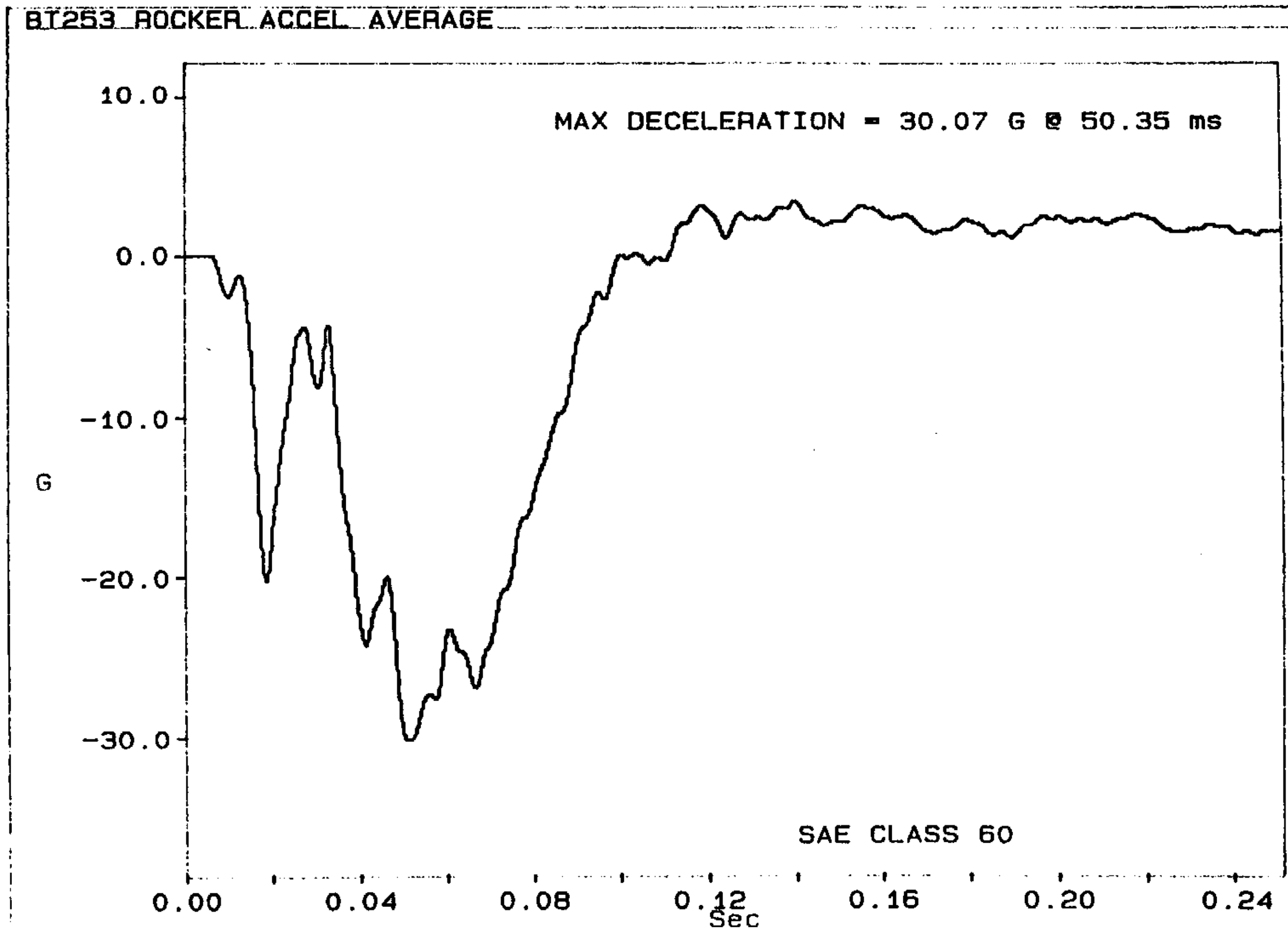


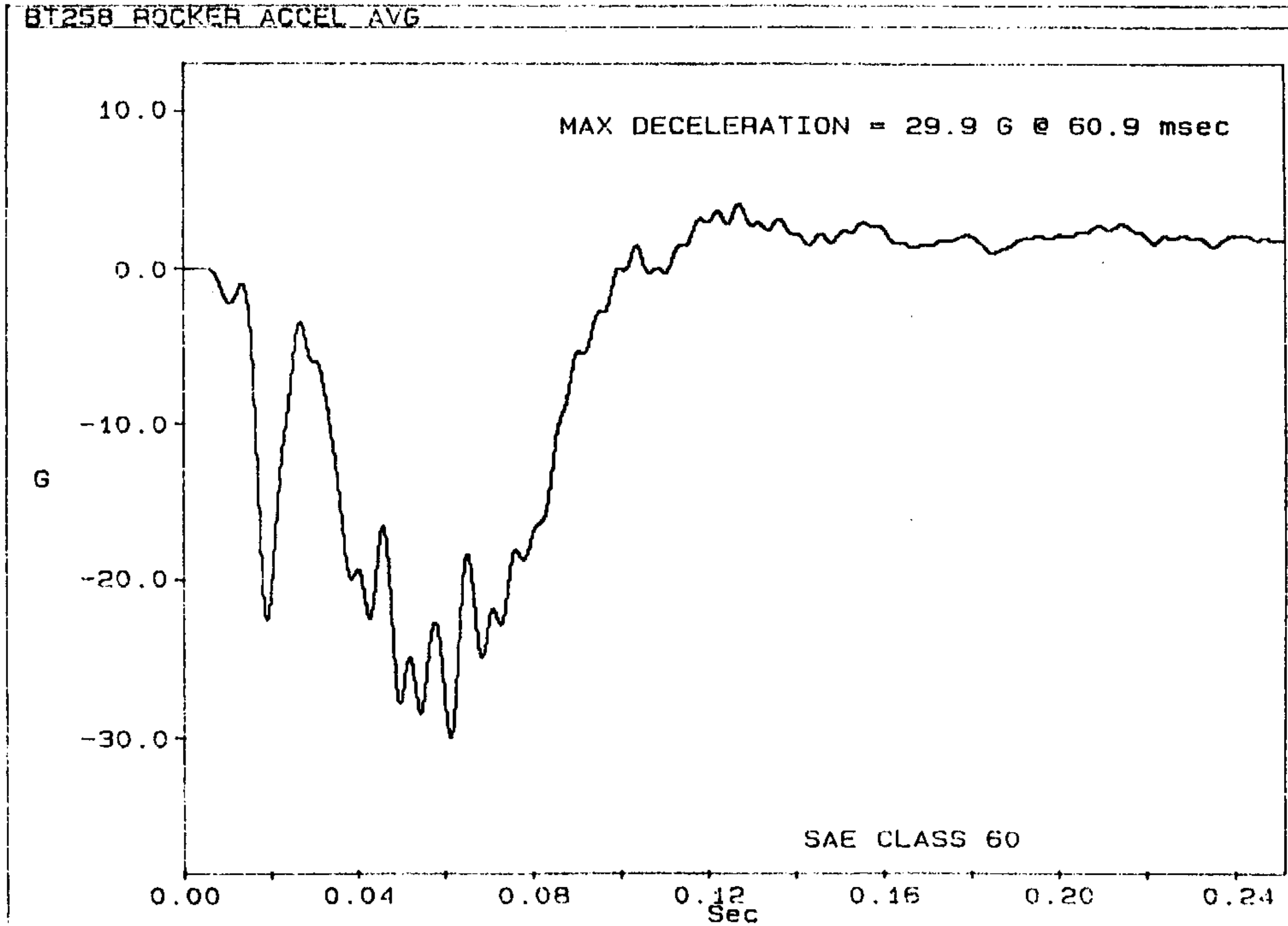
Appendix 9

Phase 3 Test Vehicle Crash Pulses



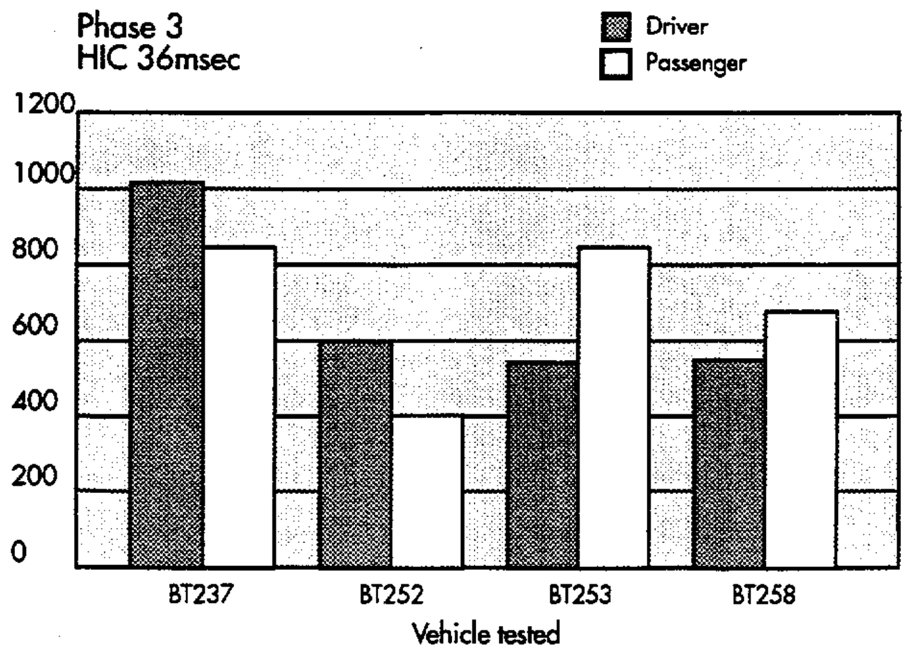
BT252 ROCKER ACCEL AVG
MAX DECEL = 26.7 G @ 48.7 msec
SAE CLASS 60
10.0
0.0
-10.0
-20.0
-30.0
G
0.00
0.04
0.08
0.12
0.16
0.20
0.24
Sec

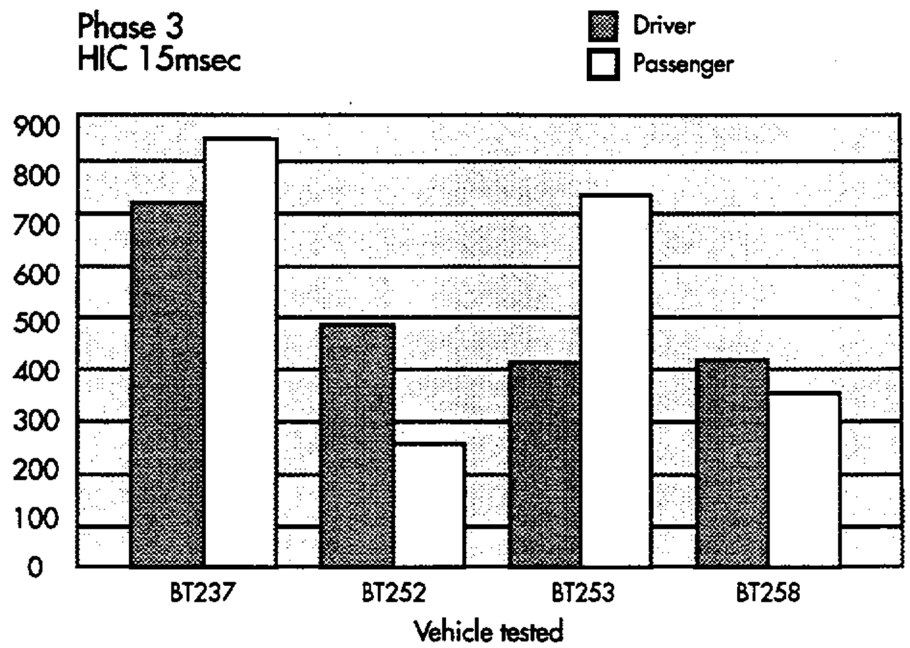

BT253 ROCKER ACCEL AVERAGE
MAX DECELERATION = 30.07 G @ 50.35 ms
10.0
0.0
-10.0
-20.0
-30.0
G
SAE CLASS 60
0.00
0.04
0.08
0.12
0.16
0.20
0.24
Sec


BT258 ROCKER ACCEL AVG
MAX DECELERATION = 29.9 G @ 60.9 msec
10.0
0.0
-10.0
-20.0
-30.0
G
SAE CLASS 60
0.00
0.04
0.08
0.12
0.16
0.20
0.24
Sec

Appendix 10

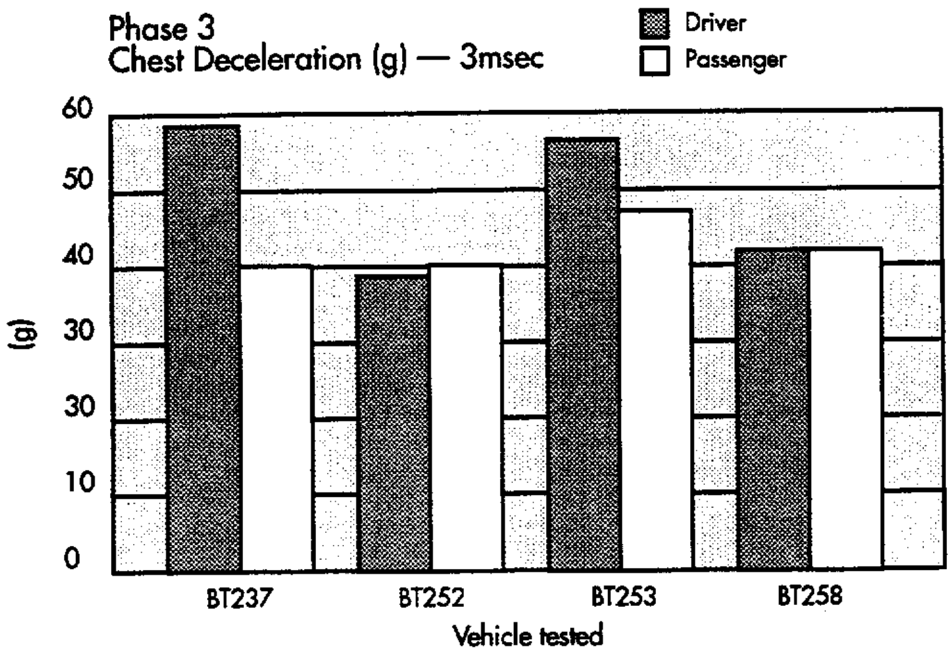
Phase 3 Bar Charts of Injury Criteria by Type



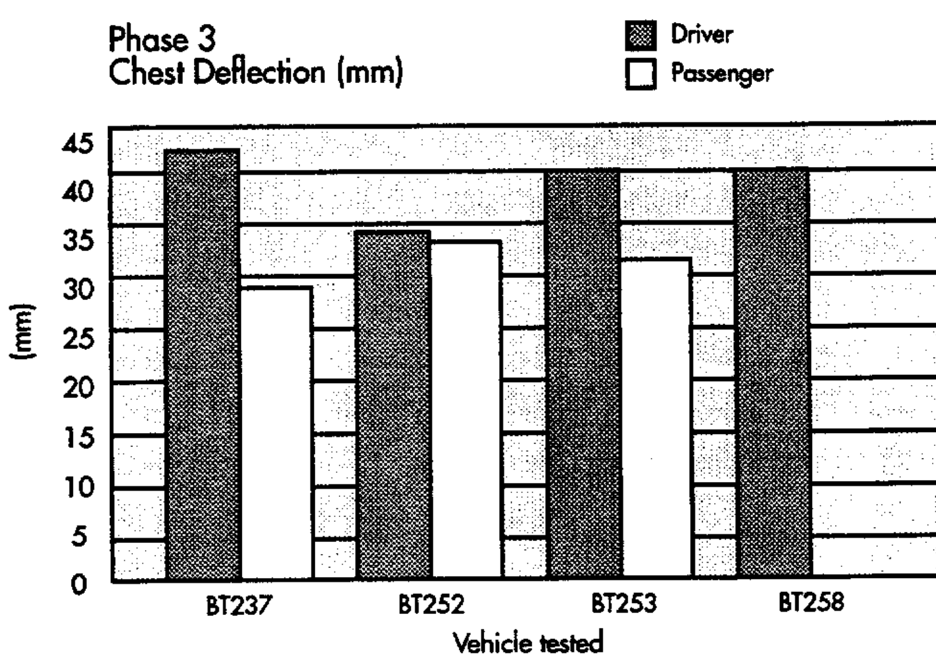


Values for the standard vehicle used in Phase 1, test BT237, are also provided.

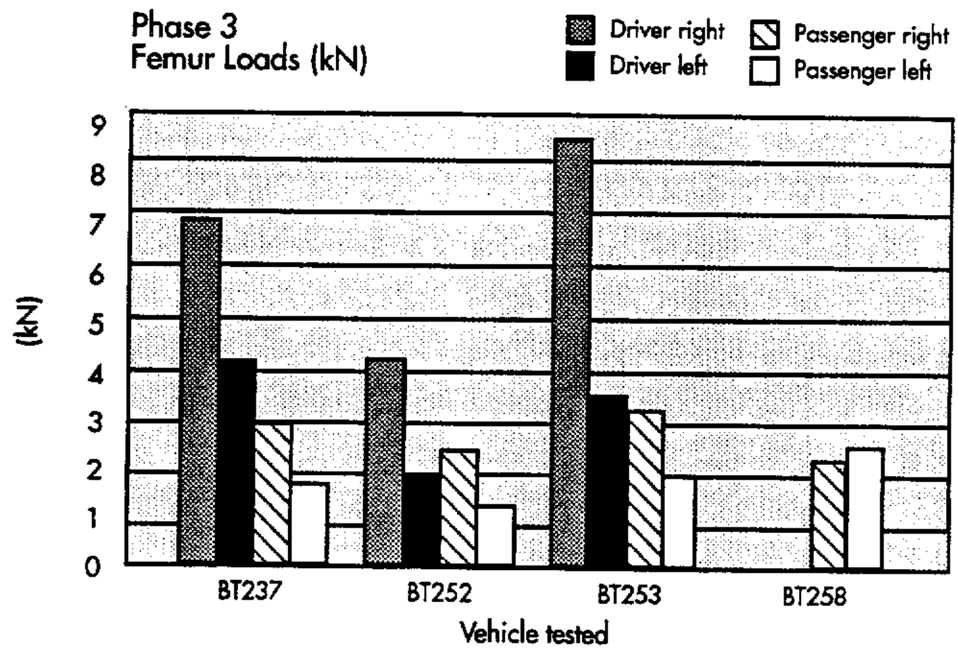
Phase 3
Chest Deceleration (g) — 3msec



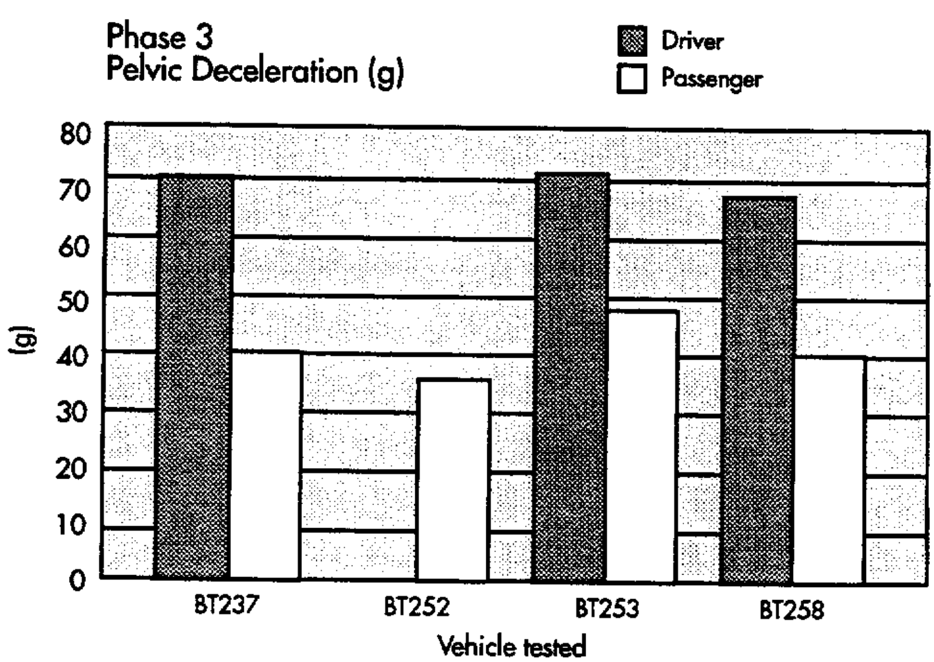
Phase 3
Chest Deflection (mm)



Values for the standard vehicle used in Phase 1, test BT237, are also provided.

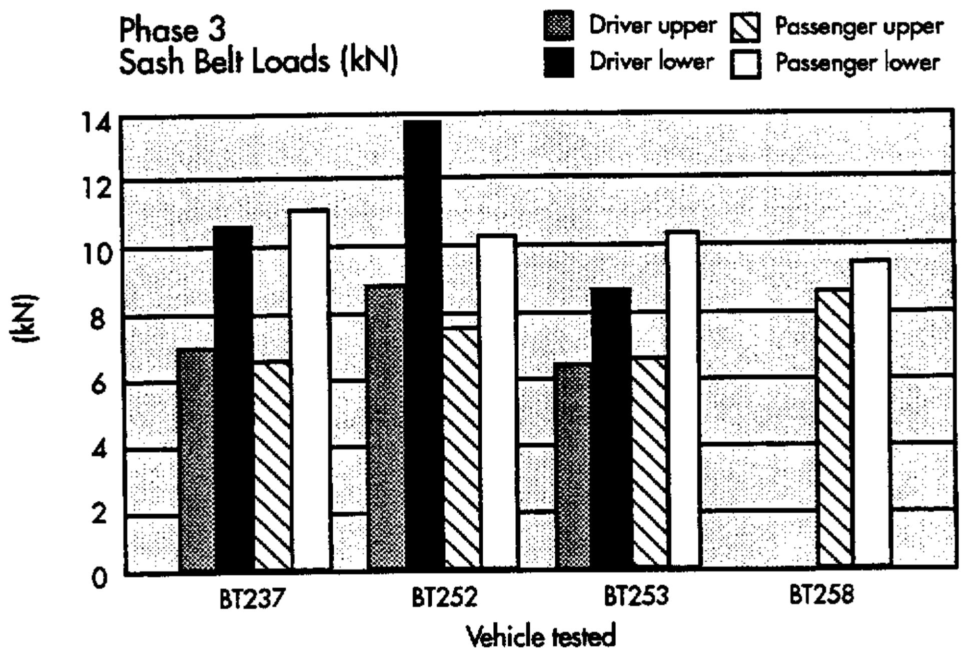


Note: Driver femur loads corrupted for BT258.

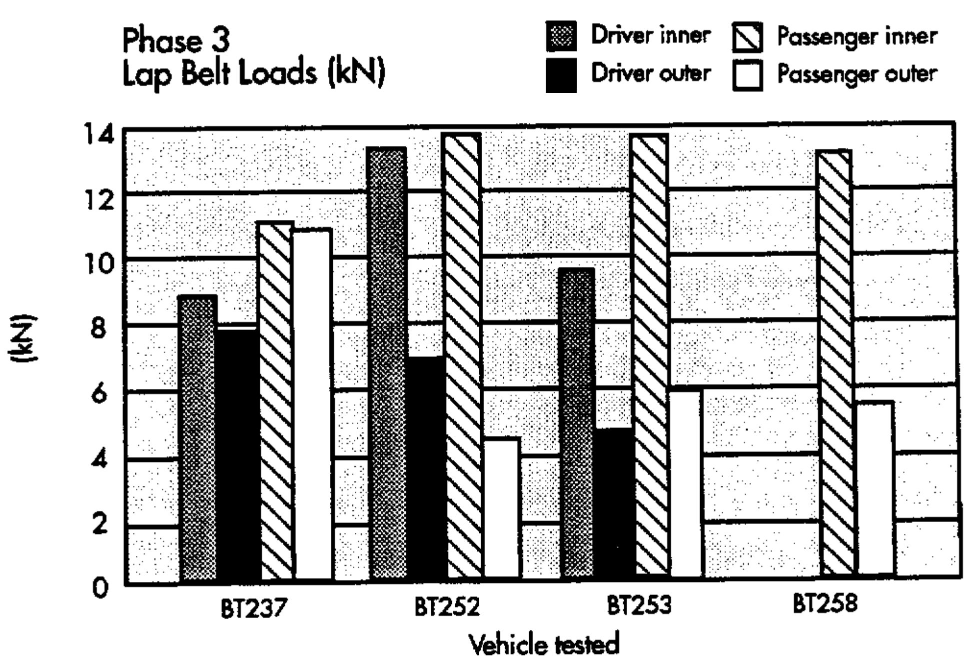


Note: Driver pelvic deceleration data lost for BT252 due to instrument failure.

Values for the standard vehicle used in Phase 1, test BT237, are also provided.



Note: Driver sash belt loads lost for BT258.



Note: Driver lapbelt loads lost for BT258.

Values for the standard vehicle used in Phase 1, test BT237, are also provided.