VEHICLE SAFETY

PAST, PRESENT AND FUTURE

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This paper discusses vehicle safety design; its history, the state of current technology as illustrated by the Commodore VT, and future technologies, and in particular the way they will effect the rescue personnel and paramedics involved in car crashes

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A HISTORY OF MOTOR VEHICLE CRASHES AND INJURIES

The first motor cars began running in the 1880s, with primitive brakes, steering and tyres, and with plate glass used for a windscreen. The potential for crashes and resulting injury was high. In 1885, as Carl Benz demonstrated his new horseless carriage invention, "he forgot to steer and smashed it against a brick wall"[1]. One of the earliest crashes resulting in fatal injury was recorded in a London newspaper in 1889. The paper reported that a vehicle was travelling down a hill at 12 to 15 mph, described by witnesses as "very high speed". As the driver tried to brake on the cobblestone street, the wooden spokes of the rear wheels fractured at the hub. All of the occupants were ejected, and the driver and a rear-seat occupant were killed. The accident caused an investigation of the materials in the wheels. Instead of quality British wood spokes, they were made from imported wood and a discussion over quality control followed[2].

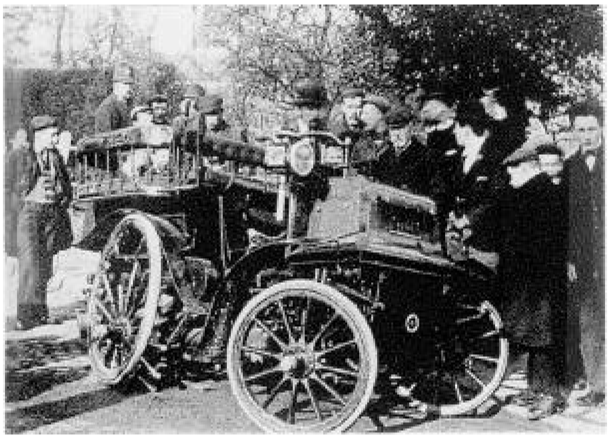

Figure 1: Car Crash Recorded in a London Newspaper in 1889

In 1895, the only two cars in Ohio, USA, collided, although there is no record of injuries to the occupants[3]. It wasn't long thereafter that the first road fatality in Australia was recorded, in February 1898. In 1910, the Argus newspaper reported "a tragic motor accident resulting in the death of a young chauffeur, Samuel Hess". Hess had swerved to avoid a cyclist, a wooden wheel had collapsed, and "the car, being under fair way, had capsized. Hess fell under the forepart of the motor, and his head was dreadfully crushed."[4]

In 1910, Barney Oldfield made his contribution to biomechanics when, after having established a speed record of 87 mph in Henry Ford's racecar 999, he alighted from the vehicle and declared "I have travelled as fast as the human body can endure". Subsequent events were to prove Oldfield's assessment somewhat conservative!

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[1] Purdy, K.W. "History of the Automobile". In Encyclopedia Britannica, Chicago Illinios, 1985, 28:773.

[2] Viano, D.C., "Causes and Control of Spinal Cord Injury in Automotive Crashes." In World Journal of Surgery, Volume16, pp 410-419, 1992.

[3] Kahil, T, Presentation at the Wayne State University Conference, Detroit, June 1999.

[4] The Argus Newspaper, Melbourne, June 25th, 1910, page 19.

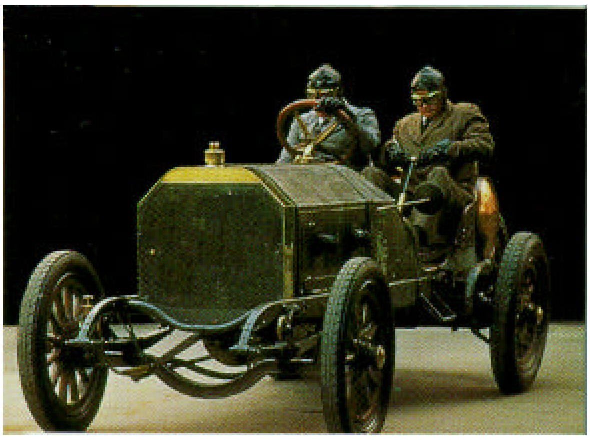

Figure 2: Barney Oldfield and Henry Ford's 999

The first barrier test was run by General Motors at the Milford Proving Ground in Michigan in 1934. At this time little was known of the cause of injury, and improvements in design were probably related more to reducing damage to vehicles than to reducing the risk of injury[5].

Figure 3: Crash Test of a 1929 Chevrolet with Unrestrained Occupants

During 1947 and 1948, Holden was testing prototypes of Australia's first car. A number of crashes occurred during this development, as all testing was conducted on public roads. Fortunately no injuries occurred. The Lang Lang Proving Ground was established in 1958, and strict safety procedures have ensured that very few crashes and resulting injuries have occurred, and no fatal injuries have occurred at the Proving Ground despite tens of millions of kilometres of testing, sometimes under extreme conditions. The first crash of a Holden resulting in injury occurred once the car was released to the public by an enthusiastic Billy Hughes on 1948. No record can be found, but more recent experience indicates that it occurred within 2 or 3 months of this date. From these early beginnings, car crash injuries increased rapidly until, by the late 1960s, they represented the major source of traumatic injury to the Australian community.

[5] Kahil, T, personal discussions, June 1999.

The consideration of vehicle safety in the automobile industry can be traced back to Hugh De Haven, an engineer and fighter pilot during the First World War. De Haven documented the features of his aircraft that allowed him to survive a crash, as well as those features that caused him injury[6]. These were the first insights into human tolerance of crash loads. John Lane of Monash University Accident Research Centre (MUARC) observed in 1942 that aircraft should be both airworthy and crashworthy, and so the term "crashworthiness" was created[7]. Automotive crash injury research was initiated by De Haven at Cornell University Medical College in New York in 1953[8]. These studies identified the major sources of occupant injury as steering assembly, instrument panel, windshield and occupant ejection.

Australia was fortunate in that the work of pioneering safety researchers Dr Michael Henderson and Dr Peter Vulcan were able to influence legislators into passing world-leading seat belt legislation in the early 1970s. The Australian community continues to benefit from this far-sighted approach. Seat belt wearing rates in Australia are amongst the highest in the world, and this has allowed Holden to implement unique designs that are based on this high belt wearing rate. The consideration of vehicle safety in the automobile industry can be traced back to Hugh De Haven, an engineer and pilot, who documented the features of his aircraft that allowed him to survive a crash during the First World War, as well as those features which caused him injury[9], the first insights into human tolerance of crash loads. John Lane of Monash University Accident Research Centre, observed in 1942 that aircraft should be both airworthy and crashworthy, and so the term "crashworthiness" was created[10]. Automotive crash injury research was initiated by De Haven at Cornell University Medical College in New York in 1953[11]. These studies identified the major sources of occupant injury as steering assembly, instrument panel, windshield and occupant ejection.

The first experiments to establish human injury tolerance began with the studies of Dr John Stapp, a U.S. Army Airforce physician, who in 1959, volunteered to be subjected to a series of tests including violent rides strapped to the front of a rocket-sled. This culminated in being stopped from 1000 km/h in less than 1.5 seconds, being subjected to sled deceleration rates of up to 49g without apparent serious or long-term injury (analysis of the film records of these tests indicate that the tip of Stapp's nose experienced approximately 200g!). Stapp demonstrated that crashes could be survived if the occupants were suitably restrained and protected from impact with the vehicle interior[12,13]. In 1956, the first Stapp Car crash Conference was held, and this continues

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6 Hasbrook, A.H. "The Historical Development of the Crash Impact Engineering Point of View", Clinical Orthopediatrics, 8:268, USA, 1956

7 Lane, J, personal communication.

8 De Haven, Hugh, "Beginnings of Crash Injury Research", Proceedings of the Thirteenth Stapp Car Crash Conference, Society of Automotive Engineers, Boston, December 1969, pp. 422 - 28.

9 Hasbrook, A.H. "The Historical Development of the Crash Impact Engineering Point of View", Clinical Orthopediatrics, 8:268, USA, 1956

10 Lane, J, personal communication, 1997.

11 De Haven, Hugh, "Beginnings of Crash Injury Research", Proceedings of the Thirteenth Stapp Car Crash Conference, Society of Automotive Engineers, Boston, December 1969, pp. 422 - 28.

12 Stapp, J.P., "Human Exposures to Linear deceleration. Part 2. The Forward-Facing Position and the Development of a Crash Harness" Air Force Technical Report 5915, USAF, Wright-Patterson AFB, Ohio, 1951.

to be a prestigious forum for research into vehicle design, human injury tolerance, and injury control. Pioneering work on seat belts was conducted in Sweden, where by 1960, 50% of private cars had seat belts fitted. The three-point safety belt system was developed by Dr. Bertil Aldman, a Swedish anesthesiologist, and Nils Bohlin, a safety engineer from Volvo.

Figure 4: Ralph Nader Giving Evidence to a US Senate Select Committee in 1965.

In 1965 America was at the peak of a love affair with high performance "muscle cars" including the Ford Mustang, the Pontiac GTO, and the Plymouth Barracuda, with large and supercharged engines, fade-prone drum brakes, but with seat belts as an infrequently selected option. Ralph Nader, a lone voice against the tide, published "Unsafe At Any Speed", focussing partly on the handling characteristics of the Chevrolet Covair. The Covair was rear engined, a more modern version of the long-lived Volkswagen Beetle. Although generally regarded in America as the people's champion against the unfettered power of the car makers, Nader began a landslide of civil law suits against US manufacturers which today inhibits any innovative approach to safety, and consequently, safety performance of US designed cars is lagging behind those leading safety development in Europe.

Australia first established a set of safety standards for new motor vehicles in the late 1960s, and subsequently established an approval system for certifying compliance in 1970. The Australian Design Rules (ADRs) are based on international standards, either American FMVSS or European ECE Regulations, except where Australian experience has encouraged some variation. For example, improved seat belt performance (in particular, protection against degradation caused by the levels of UV exposure experienced in Australia but not Europe) improved child restraints, and occupant protection in buses.

[13] Stapp, J.P., "The Hostile Kinetic Environment on Sea, On Land, In the Air and In Space." The Proceedings of the Third International Symposium on Bioastronautics and the Exploration of Space, Texas, USA, 1965.

Wayne State University in Detroit, Michigan, USA, was a pioneer in exploring human injury tolerance, and began research into head injury in 1939. The universally used laboratory measure of head injury risk, the Head Injury Criterion, or HIC, was based on data generated at Wayne State University[14]. In Australia in the early 1960's, the Australian Road Research Board funded research by Jack McLean and Tony Ryan. In-depth studies of road crashes began at MUARC in 1970.

Although the first design of an airbag has been attributed to Leonardo da Vinci[15], GM has lead in engineering experience with airbag systems. GM initiated development of airbags to provide supplemental protection to seat-belted occupants in 1969[16]. In 1973 1,000 identical Chevrolet Impalas with airbags were build and sold to gain field experience of their contribution to occupant protection. Twenty years later the remaining vehicles, retrieved from owners and wrecker's yards, provided the first evaluation of propellant stability. From 1973 to 1976, over 11,000 cars were sold with airbags fitted, before being discontinued because of lack of consumer interest. The performance of these vehicles was monitored and Mertz[17] analysed the results of 216 airbag deployments. He found that good protection was provided if the occupants were not out of position due to not wearing seat belts. The ongoing lack of acceptance by the American public of the need to wear seat belts continues to compromise the protection available to them from airbag technology as a supplementary restraint system.

[14] King, A.I., "Progress of Research on Impact Biomechanics", Journal of Biomechanical Engineering, 115, 1993.
[15] Alessandro Vezosi, director of the Museo Ideale, dedicated to the artist and inventor in the Tuscan town of Vinci, identifies a Leonardo sketch of a man with leather "bags of air" hanging from belts strapped to his body. The sketches are headed "to escape the danger of ruin". The Age, p22, 18/6/98.
[16] "Public Interest Report", GM Publication, 1991.
[17] Mertz, H.J., "Restraint Performance of the 1973-76 GM Aircushion Restraint System", in Automatic Occupant Protection Systems, SP-736, Paper No. 880400, Society of Automotive Engineers Inc., Warrendale, PA, USA, 1988.

THE BIOMECHANICS OF CRASH INJURY

The study of the biomechanics of injury began at Wayne State University, in 1939. A neurosurgeon, Dr. E.S Gurdjian of the Department of Neurosurgery, and an engineer, Professor H.R.Lissner of the College of Engineering, began an alliance to study skull fracture due to blunt impact.

Figure 10: H.R. Lissner and Steve Gurdjian

This was possibly the first collaboration between physicians and engineers to study traumatic biomechanics, and it lead to the establishment of the Wayne State Bioengineering Centre to continue their research efforts. Data generated from these first experiments lead to the generation of the Wayne State Tolerance Curve, a keystone for future head injury research.

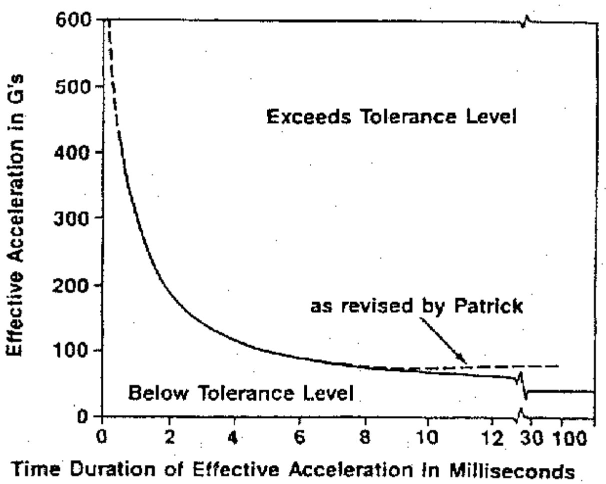

Figure 10: The Wayne State University Tolerance Curve for Impacts to the Forehead[18].

[18] Gadd, C.W., "Use of a Weighted-Impulse Criterion for Estimating Injury Hazard", Paper 660793, in Proceedings of the 10th Stapp Car Crash Conference, published by the Society of Automotive Engineers, Warrendale, PA, USA, 1966.

This curve was replotted by Gadd in 1966 and was referred to as the Gadd Severity Index. It was further refined by Versace in 1971 to become the Head Injury Criteria or HIC. HIC is now the dominant measure of head injury risk throughout the automotive industry. Wayne State researchers continue to work on understanding traumatic injury in general, and traumatic brain injury in particular. In 1943, Holbourn[19] had suggested that brain injury may be caused more by rotational motion than by translational motion. However, it was not until 1970 that Hirsh and Ommaya were able to demonstrate with animal experiments that rotational acceleration caused diffuse axonal injury[20]. They subsequently suggested that 50% of all brain injury was caused by head rotation. Current research into the causes of brain injury includes an emphasis on identifying separately; the effects of head translational motion and head rotational motion resulting from impact.

At the 1966 Stapp Conference, Charles Gadd of general Motors proposed a head injury severity index based on the Wayne State Tolerance Curve. Gadd defined his severity index as

$$\text{Severity Index} = \int a^{2.5}\, dt$$

At the 1971 Stapp Conference, John Versace of Ford proposed a modification of the Gadd Severity Index, which he called the Head Injury Criterion (HIC). This modification focuses the severity index on that part of the acceleration curve that was thought to relate to the risk of brain injury. Versace's modified index is described as

$$\text{HIC} = (t_2 - t_1) \int_{t1}^{t2} a^{2.5}/(t_2 - t_1)\, dt$$

Where t_1 and t_2 are selected to yield the maximum value. Since then, the need to restrict the time interval has been suggested, to avoid obtaining high HIC values from long duration, low level accelerations, as experienced by a vehicle occupant restrained by an airbag. The deficiencies of the derivation of HIC have been discussed in detail by a number of researchers including Newman[21]. These problems include the limited data upon which the original Wayne State Curve was based, the inclusion of poor data, poor documentation of some of the experiments, the techniques used to extrapolate and scale the data, and the definition of "effective acceleration". Whilst HIC was derived from the risk of skull fracture, it bears, at best, a crude relationship to the risk of brain injury, and most importantly, ignores head rotation, which is considered to be the cause of 50% of brain injury.

Despite the acknowledged inadequacies of HIC as a criterion for brain injury risk, it continues to be the most widely used measure of injury risk from frontal head impact. HIC has further shortcomings for application to side impact crashes, as it is based on translational acceleration during frontal impacts. Head rotation is expected to be more

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[19] Holbourn, A.H.S. "Mechanics of Head Injuries." The Lancet, Oct 9, 1943.
[20] Ommaya, A.K. "Mechanisms and Preventative Management of Head Injuries: A Paradigm for Injury Control." Proceedings of the 32nd AAMA Conference, Seattle, USA, 1988.
[21] Newman, J.A. "Head Injury Criteria in Automotive Crash Testing". SAE Paper No. 801317, 1980

prevalent during side impact crashes due to the lateral asymmetry of the head-neck complex.

In order to develop occupant protection in vehicle design, laboratory results must be correlated with field data. Measurement of injuries suffered in real world accidents requires the MUARC accident investigation team to use a different technique for injury scaling than that used by Holden when evaluating dummy response in a laboratory test. Injury scaling is a technique for assigning a numerical value to injuries. The Abbreviated Injury Scale, or AIS, was developed to aid research into motor vehicle accident trauma[22]. It is not an outcomes scale or a multiple injury scale. The scale is shown below.

Table 1: The Abbreviated Injury Scale

	BODY REGION				
AIS	**HEAD**	**THORAX**	**ABDOMEN**	**SPINE**	**EXTREMITIES**
1	HEADACHE	SINGLE RIB FX	ABDOMINAL WALL - SUPERFICIAL LACERATION	ACUTE SPRAIN	ACUTE SPRAIN
2	UNCONSCIOUS LESS THAN 1 HOUR	2-3 RIB FX STERNUM FX	SPLEEN, KIDNEY OR LIVER LACER OR CONTUSION	MINOR FX WITHOUT ANY CORD INVOLVEMENT	TIBIA OR PELVIS OR PATELLA - SIMPLE FX
3	UNCONSCIOUS 1-6 HOURS	>3 RIB FX WITH HEAMOTHOR PNEUMOTH	SPLEEN OR KIDNEY - MAJOR LACER	RUPTURED DISC WITH NERVE ROOT DAMAGE	KNEE DISLOCATION FEMUR FX
4	UNCONSCIOUS 6-24 HOURS	>3 RIB FX WITH HEAMOTH OR PNEUMOTH FLAIL CHEST	LIVER - MAJOR LACERATION	INCOMPLETE CORD SYNDROME	AMPUTATION OR CRUSH ABOVE KNEE PELVIS CRUSH (CLOSED)
5	UNCONSCIOUS MORE THAN 24 HOURS, LARGE HEAMATOMA (100cc)	AORTA LACERATION (PARTIAL TRANSECTION)	KIDNEY LIVER OR COLON RUPTURE	QUADRIPLEGIA	PELVIS CRUSH (OPEN)

AIS injury analysis does not identify the long-term social effects of head injury, and hence the cost to the individual and to the community. Irreparable brain injury (unconscious 1-6 hours) and a fractured femur both rate an AIS injury score of 3, but the consequences for the individual are dramatically different. Injury Severity Score (ISS) can be used to assess the cumulative severity of injuries. ISS is calculated as follows -

$$ISS = [(AIS_1)^2+(AIS_2)^2+(AIS_3)^2]^{½}$$

where $AIS_{1,}$ AIS_2 and AIS_3 are the 3 most serious injuries sustained by the vehicle occupant.

[22] AAMA, “The Abbreviated Injury Scale (AIS) - 1990 Revision”, Association For the Advancement of Automotive Medicine, Des Plaines, IL, USA, 1990.

A national estimate of the frequency of injuries sustained by vehicle occupants involved in car crashes in Australia (average per annum during 1988 – 1990), ranked according to the AIS scale of severity by body region are shown in the following table.

Table 2: Injury Severity by Body Region Caused by Car Crashes in Australia

BODY REGION	INJURY SEVERITY							
	Minor	Moderate	Serious	Severe	Critical	Maximum	Unknown	TOTAL
	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6		
External	0	521	7	0	10	19	0	557
Head	6201	11890	5395	3127	1599	149	0	28360
Face	48167	8193	742	52	0	0	456	57611
Neck	9731	1438	638	12	150	8	0	11977
Chest	21678	7709	6000	2637	869	205	2	39101
Abdomen-Pelvis	23518	7854	3864	562	425	6	3	36233
Spine	2467	2832	571	7	77	55	2	6011
Upper Extremity	31205	10198	2495	0	0	0	6	43904
Lower Extremity	41586	13055	6122	10	2	0	10	60786
TOTAL	184553	63690	25835	6407	3132	441	481	284540
Number of Occupants Sustaining Injury								77194

The average cost of these injuries, as developed by MUARC in 1991, utilising data from Miller[23] and rescaling to Australian costs, is shown in the following table.

Table 3: Average Cost per Injury, Australia (1991 $A,000), after re-scaling of Miller et al (1990).

BODY REGION	INJURY SEVERITY						
	Minor	Moderate	Serious	Severe	Critical	Maximum	Unknown
	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	AIS 6	
External	1.5	8.3	23.2	37.7	54.7	332.3	1.5
Head	2.1	9.8	40.3	92.9	328.2	332.3	1.5
Face	2.1	9.8	40.3	53.2	108.9	332.3	1.5
Neck	2.1	9.8	40.3	53.2	108.9	332.3	1.5
Chest	1.5	8.3	23.2	37.7	54.7	332.3	1.5
Abdomen-Pelvis	1.5	8.3	23.2	37.7	54.7	332.3	1.5
Spine	1.5	8.3	54.2	467	558.4	332.3	1.5
Upper Extremity	2.1	14.4	34.1				1.5
Lower Extremity	1.5	14.4	43.3	64	108.9		1.5

Societal Harm, as determined by the cost of the injuries, rehabilitation costs, lost income and a value on lost quality of life is an appropriate measure for establishing priorities for vehicle safety development, and for evaluating their effectiveness.

[23] Fildes et al

THE HISTORY OF HOLDEN SAFETY

In 1969, Holden established the first safety test laboratory in Australia, at the Lang Lang Proving Ground, and since that time has spent about $200M in testing, facilities and equipment to establish a world class safety test facility. General Motors has a long record of contributions to automobile safety, including such advances as safety glass, padded instrument panels, energy-absorbing steering columns[24] and infant seats. In 1977, GM developed the Hybrid III frontal test dummy, which has become the industry standard, and is universally used to evaluate the performance of restraint systems. In 1973, GM became the first automaker to establish a biomedical research laboratory in the industry, and that facility is still the only one of its type in the world. In 1990 Holden contracted Monash University Accident Research Centre (MUARC) to analyse existing Australian crash data, and to commence a continuing program of comprehensive crash investigations to provide Holden with the basis for future safety development. This new approach to the design of occupant protection, based not simply on meeting government regulations (which consider only an average sized young male), but on providing the best protection for all occupants in all crashes. At the same time, Holden contracted a research group at RMIT University to design optimising software to be used in the design of the Commodore restraint system. The restraint system includes seat belts, airbag and seats. The system characteristics to be optimised include seat belt webbing stiffness, buckle pretensioner and webbing clamp characteristics, airbag deployment time, inflation rate, inflation pressure, airbag vent size, tether length, unfolding pattern, seat shape and stiffness, and anti-submarining ramp shape. All of these factors have to be considered against the different needs of males and females, young and old, and children, in the large range of crash types and severities that occur in the real world.

Based on this research, Holden developed the first Australian airbag system, released in the VR Commodore in 1995. This is the only system developed specifically for drivers wearing seat belts. Further learnings from this on-going research were incorporated into the VT Commodore, released in 1997. This vehicle incorporated two important, world leading safety designs. The first was a front structure developed to manage crash energy more efficiently, and to tailor the crash pulse to reduce loads on occupants. The second break-through was a restraint system with characteristics optimised for minimum societal Harm, to provide maximum community protection. Following these leading front crash protection developments, in 1998 Holden was the first Australian maker to introduce side impact airbags. These side impact airbags were developed specifically to provide head and neck protection, the area identified by MUARC research as of suffering the most Harm in side impact crashes in Australia.

The development of this new approach to the design of frontal crash protection, based on achieving the best community protection, has now lead to consideration of how to apply this approach to side impact crash protection. A major research project is currently under-way, involving Holden, MUARC and others, including a team of

[24] Skeels, P.C., and Hanson, H.L., "The General Motors Energy Absorbing Steering Column: a Case History". Proceedings of the Tenth Stapp Car Crash Conference, Society of Automotive Engineers, Paper No. 660785. Holloman Air Force Base, New Mexico, November 1966.

international safety researchers. Holden is progressively incorporating the insights gained from this research into the design of future model Holden vehicles.

The benefits of the Holden safety design for community protection have now been quantified by MUARC research into 5 years of Commodore crashes resulting in airbag deployment. MUARC have estimated that, on average, whenever a Commodore driver's airbag has deployed, the driver has avoided $12,000 hospital costs, and a total of $20,000 of Harm.

CAR CRASHES IN AUSTRALIA

Car crashes are causing increasing concern in Australia, as evidenced by frequent media coverage and advertising sponsored by the Transport Accident Commission. Over the past decade, over 30,000 people have been killed in motor vehicle crashes in Australia, and over 300,000 seriously injured[25]. It is estimated that road crashes cost the Australian community $6 billion per year[26], with brain injury alone costing $800 million. The focus of road safety in the past has been on reducing the road toll. This resulted in the introduction of legislation making the wearing of seat belts compulsory in Victoria in 1970. This was world-leading approach that has been of great benefit to the Australian community. More recently, it is being recognised that serious injury, particularly long term and irrecoverable injury to the head and neck are a major concern for the community. The priority is now on reducing the Societal Harm caused by car crashes. The introduction of airbags to provide increased protection in frontal crashes is contributing to injury reduction in serious crashes, particularly for head and neck injury. MUARC currently estimate that for the Commodore, Societal Harm is reduced by $20,000.

In 1997, in Australia, there were 1,768 persons killed in 1,603 road crashes[27]. It is estimated that approximately 800 of these were killed in side impact crashes[28]. By comparison, in the USA, approximately 8,000 car occupants are killed annually. While side impact crashes represent only a small proportion of total car crashes (in Victoria, 65% frontal crashes, 14% side impact crashes), they cause almost as many fatalities (51% of fatalities in frontal crashes, 45% in side impact crashes). This data is included in the Table below. Note that Police Data includes both crashes resulting in injury and without injury, the Crashed Vehicle File (CVF) contains only crashes that resulted in occupant hospitalisation or fatality, and the Fatal File and the USA-FARS files contain only crashes which resulted in occupant fatality. These data clearly emphasis the greater severity of side impact crashes. A comparison of fatalities resulting from the range of crash types in USA and Australia is shown in the table below.

[25] Federal Office of Road Safety. Fatality File", Statistics and Analysis Section, Canberra, Australia, 1992.
[26] Federal Office of Road Safety. "Monthly Bulletin", Statistics and Analysis Section, Canberra, Australia, March 1995.
[27] Road Fatalities in Australia: 1997 Statistical Summary. Federal Office of Road Safety, Department of Transport, Canberra, Australia, 1998.
[28] Personal communication with Dr B.G. Fildes, 1998, estimated from FORS Fatal Files.

Table 4: Type of Crash Configurations in Victoria Using Various Databases Available[29]

Crash Type	Police Data	CVF	Fatal File	USA-FARS
Frontal	**65%**	**60%**	**51%**	**44%**
Side Impact	**14%**	**35%**	**45%**	**29%**
Rear Impact	**11%**	**0%**	**2%**	**3%**
Rollover	**10%**	**5%**	**2%**	**24%**

Table 5: Fatal Injuries from Side Impact Crashes in Australia Compared to USA, Passenger Car and Light Truck Occupants.

BODY REGION OF INJURY	PERCENTAGE OF FATALITIES	
	USA	AUSTRALIA
Head	47	37
Chest	29	15
Neck/Spine	11	5
Abdomen	8	2
Unknown	5	7
Total Number	7,767	578

(Sources: MUARC analysis of 1988 NASS Statistics from USA, Australian FORS Fatal File, 1988.)

The above data illustrates the marked difference between car crashes in Australia and the USA, presumably due to the differences in road systems in the two countries. Unlike the US freeway system, the majority of the Australian highway system is undivided 2 lane roads, and thus frontal crashes will occur more frequently in Australia. Side impact crashes in Australia, whilst proportionately less frequent, cause almost as many fatalities as frontal crashes. The increased severity of side impact crashes in Australia is presumably related to the larger proportion of uncontrolled intersections, and infrequent use of overpasses commonly used in USA to avoid intersection collisions.

Although the annual crash fatalities, the so-called “road toll” is of great concern, and has been the focus of media and police road safety initiatives for many years, the cost to the individual and to the community of the injuries caused in car crashes has been overlooked. For every fatality, approximately 100 people are injured, and some of these suffer long-term and irrecoverable injuries, which can have devastating effects

[29] Fildes, B.G., “Crash and Injury Patterns to Australian Car Occupants.” In Biomechanics of Injury and Vehicle Crashworthiness Short Course, Monash University, Melbourne, Australia, 1998.

on the individual and the immediate family, as well as causing a significant cost to the community. Some measure of the cost of car crashes is required in order to ensure the appropriate priority is given to strategies for reducing the fatalities and injuries caused. One such measure is that of Societal Harm, a technique developed by Miller[30]

HOLDEN COMMODORE SAFETY

The VT Commodore has two major advances in occupant safety. These advances come from the first-known application of two new, computer based technologies. The first is an important new concept in the design of the body front structure for crash energy management. The second is a new approach to restraint system design, which gives optimised protection for minimum societal Harm. As a result of these and other changes, VT safety is world class, and represents a paradigm shift from previous vehicles.

The new body front structure incorporates a number of new design concepts. It is based on Holden's growing knowledge of vehicle safety in Australia, from the research conducted for us by Monash University's Road Accident Research Centre. Holden is among the technology leaders in crash simulation, and this capability has been utilised in developing the body structure of the Commodore VT.

The front structure design addresses a number of real world safety issues. For maximum occupant protection, the vehicle front structure must incorporate four competing characteristics -

1. An initially soft front structure is required to keep crash forces as low as possible in the frequent low speed crashes that occur.
2. A stiffer structure that generates moderate and uniform forces in high speed crashes is required to absorb the energy efficiently at minimum risk to the occupants.
3. A very stiff structure is needed to manage extreme crash energy, without compromising occupant survival space.
4. Finally, a structure which is not aggressive toward other, particularly smaller, vehicles.

The design characteristics of the front structure include -

- Straight frames, which are very stable and have a very large, computer generated cross-section that is highly efficient in absorbing crash energy. The frames taper to increasing size at the front of the car.
- Small deformities designed as crush initiators to ensure smooth, continuous collapse of the frames.

[30] Miller, T.R., Pindus, N.M., Leon, T.S., Douglass, J.B. "Motor Vehicle Injury Costs by Region and Severity". Proceedings of the 34th Annual Conference of the Association for the Advancement of Automotive Medicine, Scottsdale, AZ, USA, 1990.

- The frames are spread out at an angle, and are connected by a large, closed section front beam. The structure is designed for the real world offset and angled crashes, not for a specific barrier test.
- A brake-away feature of the front suspension cross-member attachment to the frames provides additional crush distance and hence large energy management.

The side structure also, is designed for real world safety. It gives improved energy management for car, truck and pole collisions. Energy management does not mean making the body stronger or stiffer. It requires a stiffness distribution and energy management distribution around the structure to reduce the occupant impact severity. There is a substantial, closed section roof frame, which is part of a continuous frame across the side of the vehicle. The structure incorporates full-length pillar reinforcements, continuous load paths through the joints. Floor and roof frames provide lateral load paths. In side impact crashes, the real risk in Australia is long-term, and irrecoverable head and neck injury. Improving the management of crash energy into this structure minimises this injury risk.

The second area of new technology application is in the optimisation of the restraint system to minimise the risk of injury to all occupants of the VT Commodore. Fatality reduction was a very appropriate focus in the 1960’s and 1970’s, and lead to compulsory seat belt wearing legislation, which has been of great benefit to our community. Twenty five years on, however, more is known about long term and irrecoverable injury, and the resultant cost to the individual and the community. Government legislation tests the injury risk to the averaged size male sitting in the mid-seating position in a crash into a 100 tonne concrete block at 48 km/h. This does not recognise that half of vehicle occupants are female, and that crashes vary in type and severity. The Commodore airbag system was designed not just to meet regulation, or to reduce fatality risk, but in addition, to reduce injury risk based on minimum societal Harm. With the assistance of a research project at RMIT, Holden has developed a new computer technique known as Optimising for Minimum Societal Harm. Using this technique, 100,000 possible combinations of seat belt types, seat cushion designs, and airbag performance characteristics were evaluated to select the system which, in combination with the new front structure performance, gives the best protection the whole community of occupants.

A key input to this process is Holden’s growing knowledge of injury risk in Australia, from the case-by-case detailed crash investigation program conducted for Holden by Monash University Accident Research Centre. Few other manufacturers in the world have such detailed programs, and this is the only one of its type in Australia. It provides the critical validation of laboratory testing and computer simulation, plus the information needed to make the important advances demonstrated in the Commodore.

The restraint system includes -

- Front seat belts incorporate pyrotechnic buckle pretensioners, webbing clamps and soft webbing.
- Retracting lap/sash belt in the centre rear seating position on the station wagon.

- Rear seat back strength developed to provide rear occupant protection in both sedan and wagon from severe luggage impact.
- Front and rear seat structures are shaped to support the occupant in a crash, and prevent small occupants in particular ‘submarining’, or sliding beneath the lap section of the belt.
- The airbags inflate with minimum aggressivity, and the airbags incorporate state of the art bag fold and tether design to protect small occupants, females and out of position occupants.
- Two stage restraint system control, which fires the buckle pretensioners in moderate crashes, and airbags plus buckle pretensioners in severe crashes.

FUTURE SAFETY DEVELOPMENT

Community expectations of reduced fuel consumption and emissions will result in future vehicles utilising a range of new materials in order to achieve the mass reduction required to support these increased performance levels. New materials such as aluminium, magnesium, stainless steel and plastic will be increasingly utilised to reduce vehicle mass. Some of the properties of these materials, including flamability and toxicity will provide new challenges to rescue services. They will require rescue services to develop new approaches to crashed vehicle emergency access. In addition, the next generation vehicles will utilise higher voltage electrical systems. Hybrid powertrain vehicles, electric and fuel cell powered vehicles may use 40 volt or even as high as 200 volt electric systems. This will require new procedures and safety precautions.

Other characteristics resulting from the rapid growth of on-board computing power and supporting electronics should provide rescue services with some useful assistance. The future Commodore will able to identify vehicle occupants by personalised electronic key or thumb print, by seat location and mass sensors, and by infra-red sensing of the interior. This information will be used to automatically adjust seat position, mirrors, radio and air conditioning settings, and vehicle performance characteristics. For example, one family member may prefer firm ride and fast transmissions shifts for performance, another may prefer softer ride and smoother shifts for comfort, and a third member may have the performance restricted to a level appropriate to an inexperienced driver. These characteristics will be automatically set as the driver approaches the car. This same technology will also provide the crash computer with a biomedical profile of the occupants, and facilitate the calculation of injury risk. The future Commodore will also have a sophisticated telematics system that will provide not only the convenience of navigation, but the ability to transmit a large amounts of information from the car back to a central Holden computer, and if necessary, on to the rescue organisation. The future car crash computer will be supported by a range of radar sensors, providing crash avoidance functions such as intelligent cruise control (maintaining a safe distance behind the car in front), night vision and crash sensing. In the event of a crash, the crash computer will notify the emergency services of the crash. The information provided will include more than just the crash location. The crash computer will have evaluated the crash type and severity. Using the information about the vehicle occupants collected and stored when the journey began, the crash computer will estimate the type and severity of injuries that were sustained by the occupants. The medical files of the injured occupants will be downloaded from Holden’s central file, identifying any health risks or medication required. In particular, a prediction of occult injury will be made. For example, if the crash computer senses that the driver was not wearing a seat belt, it would warn the rescue team to expect abdominal injury. If the car was involved in a side impact crash above a certain severity level, and if the occupants were older and at risk, it would warn the rescue team of the potential for aortic rupture in the occupants nearest to the impact. This additional information should provide rescue teams with increased ability to achieve successful outcomes from their rescue work.

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