

EFFECTIVENESS OF AIRBAGS IN AUSTRALIA

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ABSTRACT

General Motors - Holden's Automotive (Holden) was the first Australian manufacturer to introduce a package of new safety features with the release of the VR Commodore, including a driver's side airbag. This was followed two years later with a passenger airbag, released in the VS model. These airbags, in conjunction with an improved seat belt system, have the distinction of being specifically designed for Australian driving and accident conditions and as a consequence are different to those found in vehicles designed overseas. To determine the effectiveness of these systems the investigation of a number of field accidents has been conducted. The preliminary results of this work, although not all statistically significant, are very encouraging and suggest that the airbags have had a positive effect on reducing occupant injury with few of the negative side effects that are now being identified with some foreign airbag systems.

INTRODUCTION

There has been a marked increase recently in the safety technology of Australian passenger cars aimed at improving occupant protection. The VR Commodore, released in 1993, heralded a number of significant advances in local automotive safety. This primarily consisted of the driver's airbag (SRS system), the first to be released on a locally built vehicle and the incorporation of webbing clamps on the seat belts fitted at the front seating positions. This was followed in 1995 with the VS Commodore which featured a front passenger SRS system, again the first for a local vehicle. The development of these restraints represented a major challenge for Holden's Advanced Engineering group as the primary design objectives were to produce systems that would best suit Australia's driving and accident environment, not simply duplicate American or European

designs, and act to supplement the protection provided by the seat belts.

To gauge the effectiveness of the GMH airbags, the Monash University Accident Research Centre (MUARC) was commissioned to inspect all crashes in the Eastern States of Australia where the airbag(s) was deployed. Similar severity non-airbag VR Commodore crashes and a sample of previous VN and VP models were also inspected as controls. Inspections have been continuous since the release of these vehicles and there are currently 64 airbag cases, 40 non-airbag cases and 54 previous model controls. The data collected from these crashes have been analysed to determine the success of the restraint systems and the results so far have been very positive.

Design Philosophy of Restraint Systems

Australia has a unique driving and accident environment. Two points in particular characterise the differences between the local situation and that experienced overseas: (i) there is a high incidence of frontal collisions, and (ii) there are high rates of seat belt wearing. As a result of these differences, an automotive restraint system designed specifically to suit the local environment will be different to that found in vehicles from other countries and the restraints employed in the Commodore are a good example of this.

The high rate of frontal impacts experienced in Australia, in comparison to other collision modes, is the result of a less sophisticated road network. In contrast to the road systems found in some other countries, such as the US, there are vast amounts of undivided roads and more roadside hazards, such as trees and poles. This results in a high incidence of frontal accidents, including offset and oblique impacts and is well illustrated by the fact that in the state of Victoria 56% of all collisions in which one or more of the vehicle occupants are injured results from a frontal crash while in the US only 39% of such collisions are attributed to frontal impacts. This trend is even more pronounced when looking at serious (at least one occupant admitted to hospital) and fatal collisions where over 62% of such injuries are attributed to frontal impacts.

Australia also has a high rate of seat belt wearing; over 95% for front seat occupants and over 80% for rear seat occupants. This is a result of legislation that came into effect in the state of Victoria on 22 December 1970 which mandated the use of belts for the first time in a state with a substantial vehicle population. It is estimated

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that this legislation resulted in a 12% reduction in the number of driver and front seat passenger deaths by 1971 when the overall usage rate was only 50%. This legislation was soon adopted by the other Australian states and territories and today some 40 countries worldwide have mandatory wearing laws.

These two points have had a major influence on the design of the restraint systems employed in the Commodore and allowed two important assumptions to be made early in the development of these systems: (i) the airbag trigger threshold would be set such that they only deployed when an accident was of such severity that the seat belts alone could not offer complete protection, and (ii) the airbags would be tuned to inflate as less aggressively as possible. As a consequence, fundamentally different restraint systems have been implemented in the Commodore than are typically found in many overseas vehicles, especially those developed for unrestrained occupants. In particular, the airbags have been specifically designed to offer supplementary protection to that provided by the seat belts.

Seat Belt Design

Given that seat belts are so frequently utilised in this country it is important that they provide the primary means of protecting vehicle occupants by offering the maximum possible protection. The webbing clamp seat belts employed in the front seating positions represent a significant improvement over the conventional Emergency Locking Retractor (ELR) design of belt. They incorporate a metal clamp on top of the retractor which reduces both the payout and spooling of the webbing as the belt is loaded in an accident. This restricted payout has the benefit of providing more controlled occupant kinematics and reduces the risk of the occupants striking the steering wheel or dash. In comparison to ELRs, the webbing clamps release around 100 mm less webbing in a standard ADR 69/00 (48 km/h 0° frontal) barrier test.

SRS Sensing System

The airbags in the Commodore are triggered by a single point Sensing and Diagnostic Module (SDM). This unit provides a centralised, self-contained sensing and triggering system that is capable of distinguishing between a minor parking bump and a potentially injurious collision. It also performs a diagnostic role by continually testing the SRS system and assisting service personnel by indicating the cause and location of any faults. It is fitted with an energy reserve capacity such

that its function is temporally preserved in a collision if power to the module is lost and most importantly provides superior collision sensing with the Commodore's crash pulse. Through a range of impacts the SDM is capable of triggering the airbags within acceptable time limits to ensure that the occupants received the maximum benefits of the airbags. This is an important point as an SRS system that cannot deploy within the necessary time will not only be of much less benefit but may present an injury risk to the occupants if they contact the airbag cushions while they are still inflating.

The concept behind the sensing operation of an SDM is relatively straight forward. Once a vehicle becomes involved in a collision, an accelerometer measures the resulting deceleration as the vehicle's structure crushes. This signal is mathematically processed and compared with predetermined thresholds based on jerk, acceleration, velocity and energy criteria. At the same time, a simple mechanical deceleration switch is checked. If the requirements of both the sensing algorithm and the mechanical switch are met, indicating that the vehicle is involved in a severe frontal collision, the airbags are deployed. If only the accelerometer algorithm or the mechanical switch are activated then the airbags are not fired. The purpose of the mechanical switch is to act as a guard against accidental firing if the vehicle is subject to intense electro-magnetic interference as is often the case near communications towers and airport radars, etc. Vehicles fitted with both driver and passenger SRS systems will deploy both airbags simultaneously when involved in severe collisions.

The thresholds with which the accelerometer signal is compared are derived from vehicle barrier tests. Each test produces a distinct 'crash pulse' (deceleration profile) as the various impacts cause the body of the vehicle to deform in different ways. Hence a range of tests must be performed to produce a full SDM calibration, including: frontal, oblique, off-set, pole and under-ride impacts. A series of 'non-deploy' tests must also be performed to ensure that the SDM will not trigger in situations where airbag inflation would be of no benefit to the occupants, including low speed impacts or when the vehicle is being exposed to severe driving conditions, such as through pot-holed roads or during emergency braking over rough surfaces. Approximately 30 barrier tests were conducted in the development of the VR Commodore's sensing system and another 15 in the development of the VS Commodore's system.

Given that the Commodore's SRS systems have been developed for belted occupants, the airbag deployment

thresholds have been set relatively high. The system's no-fire limit (the equivalent frontal barrier impact below which the airbags should not deploy) is around 20 km/h while the all-fire limit (the equivalent frontal barrier impact above which the airbags should always deploy) is approximately 28 km/h; between these limits the airbags may deploy depending upon the circumstances of the impact. This is significantly higher than the thresholds employed in some other restraint systems; some vehicles have no-fire thresholds of 12 km/h.

Airbag Design

The airbag modules in the Commodore are designed to deploy as less aggressively as possible while still providing the necessary protection to occupants of different size, weight and sex whom will be potentially involved in a variety of collisions. Great efforts have been taken in the development of the inflators and cushions to ensure they present as little risk as possible to the occupants during inflation. Since the airbags have been designed to operate in conjunction with the seat belts, they are only required to decelerate the occupant's head and upper torso as the primary retardation is provided by the belts. This is fundamentally different to many other airbag designs especially those used to protect unrestrained occupants. Such systems typically utilise high performance inflators in conjunction with cushions with low venting rates. This combination ensures that the airbags are sufficiently stiff to decelerate unbelted occupants. While such systems operate well in standard accidents they can present an increased risk to occupants who are close to the airbags when they deploy, such as small female drivers. Such occupants are increasingly being identified as suffering inflation induced injuries (I^a) which are injuries directly attributed to the deployment of the airbags.

Both the driver and passenger airbags in the Commodore employ sodium azide inflators. The driver's unit uses a moderate performance inflator which yields a peak pressure of 300 kPa in a standard 1 cubic foot tank test. A fully coated, full-sized cushion is employed which has a volume of 65 litres when completely inflated. Four 275 mm tethers and an innovative folding pattern are used to control the shape of the cushion during deployment and prevent it from inflating directly towards the driver. The tethers consist of strips of material that connect the front face of the cushion to the module housing and prevent it from deploying beyond a predetermined limit. The folding pattern helps ensure that a flat surface is presented to the driver such that the cushion has a lower tendency to balloon around their

neck. Two 45 mm diameter vents allow the cushion to rapidly deflate as the driver contacts it which decelerates the occupant's head and upper torso as gently as possible.

The passenger airbag is significantly larger and displaces a volume of 120 litres when fully inflated. However it also employs a relatively gentle inflator which produces a peak pressure of 240 kPa in a standard 100 litre tank test. Again, tethers panels and a specific folding pattern are used to control its shape during deployment. Two 30 mm vents allow the gas to escape from the cushion as the passenger contacts the bag.

Approximately 150 Hyge sled tests were conducted in the development of the restraint systems employed in the VR and VS Commodores. These tests, as with the barrier tests, were performed at Holden's Lang Lang Proving Ground, south east of Melbourne and utilised the then recently purchased 'family' of Hybrid III dummies which consists of several 50th percentile male, a 5th percentile female, a 95th percentile male and several child dummies. The performance of all these dummy types was evaluated to ensure that the maximum protection would be offered to all occupant not just those represented in federal certification crash tests.

ANALYSIS OF EFFECTIVENESS

An analysis was undertaken for GMH by the Monash University Accident Research Centre to determine the effectiveness of the GMH airbag fitted in Australian Commodores. Data were collected on *three* versions of Holden Commodores involved in frontal crashes of minimum tow-away crash severity, namely (1), baseline cars (models VN & VP, the predecessor to the first airbag model); (2), airbag models VR & VS, where the optional airbag was fitted; and (3), non-airbag VR and VS models where the airbag option was not taken up. A total of 158 eligible crashes were inspected comprising 54 baseline, 64 airbag and 40 non-airbag cars.

Overall Findings

There were no noticeable differences between the two samples in terms of type of frontal crash and breakdown of driver age and sex. There were also no marked differences in seat belt wearing rates either between airbag or non-airbag cases which is reassuring as it suggests that the presence of airbags does not mean that drivers are less likely to wear their seat belts in these cars. The number of kilometres travelled was, however, considerably higher for the baseline cars than the more recent VR and VS models, simply because they were an

older fleet at the time of inspection with higher exposure. However, this was not felt to be a major problem for this analysis. Given these findings, it was concluded that combining the baseline and non-airbag cases to form no airbag controls was appropriate in the subsequent analysis.

Figure 1 shows the delta-V distributions for the airbag and control (baseline plus non-airbag) cases where delta-V was either known or could be calculated (69% of cases). While there were differences between the two distributions, the modal values were similar (41-50km/h) and there was no appreciable differences in mean impact velocity between both categories up to 61km/h (Airbag mean = 38.6; Control mean = 38.4). The delta-V values above 61km/h were grossly different as was the outcome severity of these occupants. For the nine control occupants, their delta-V values ranged from 61km/h to 102km/h and two-thirds were hospitalised and the rest only required A&E department treatment while the one severe airbag crash was at 108km/h and the driver was killed. Because it was felt that the airbag was less likely to be effective at these high crash severities and the bias that including these few high delta-V cases was likely to have on the results, the analysis was confined to crash severities below 60km/h. Thus, the outcome for drivers in 63 airbag and 85 non-airbag control vehicles was compared as a measure of airbag effectiveness among GM Holden Commodores.

Injury Analysis

The body region injury outcomes of the airbag and non airbag drivers involved in tow-away frontal collisions is shown in Table 1. Drivers in airbag deployed Commodores had significantly fewer chest injuries of all severities ($\chi^2=5.8$, $p<.05$) and there was a trend towards fewer head, face and abdomen-pelvic injuries, albeit not statistically significant. Head injuries of moderate severity and all upper extremity injuries did approached significance ($\chi^2=2.8$, $p<.10$ for both comparisons). The increase in upper extremity injuries, in particular, was most noteworthy where airbag occupants were about 14% more likely to sustain these injuries than their non-airbag counterparts. However, this was confined exclusively to minor (AIS 1) injuries. The increase in the percent of spinal injuries for airbag occupants, while not significant, was of some concern. On closer examination, the two severe spinal injuries to the airbag occupants were fractures to T8/9 in the thoracic region with unknown sources of injury while the one severe spinal injury was a fractured L2 vertebrae to the lower back, also of unknown

source. Because of the low number of cases, these findings should be taken as indicative only at this stage.

Tables 2 further shows the mean ISS, probability of injury and average Harm sustained for these drivers in frontal crashes. Of particular note, drivers in airbag deployed Commodores generally had a lower ISS score and corresponding lower probabilities of injury at each level than did drivers of non airbag crashed Commodores. The Harm savings to the driver for airbag equipped vehicles was A\$20,000 per crash in A\$1995 prices (Fildes, Digges, Carr, Dye & Vulcan 1995).

Source of Injury

The source of injury for drivers in airbag and non airbag GM-Holden Commodores involved in frontal crashes is shown in Table 3. There were only a few differences in the source of injury patterns between airbag and control cases. Airbag occupants had slightly fewer contacts with the steering assembly, especially those that resulted in severe injuries but they had more contacts with the windscreen and header rail. They also had more contacts with the roof but fewer with the door panel. Of particular note, airbag occupants had slightly fewer seatbelt induced injuries. 14% of their injuries, albeit of minor (AIS 1) severity, were from contact with the airbag itself. There were too few injury cases available to break these findings down any further to examine specific body region injuries by contact source.

DISCUSSION

Australian passenger cars have recently seen a significant increase in the level of protection afforded to their occupants. Holden was the first vehicle manufacturer to develop and introduce advanced restraint systems that would best suit Australia's driving and accident environment. As seat belt wearing rates in Australia are relatively high, the Holden airbags have been specifically designed to supplement the protection provided by the belts.

While limited in the amount of data available, the GMH Commodore airbag effectiveness analysis was encouraging. There was a significant reduction in chest injuries and an indication of a reduction in serious head injuries for those injured in airbag Commodores, compared to similar non-airbag controls. The reduction in chest and possibly head injuries for drivers with deployed airbags confirmed the beneficial effects of these

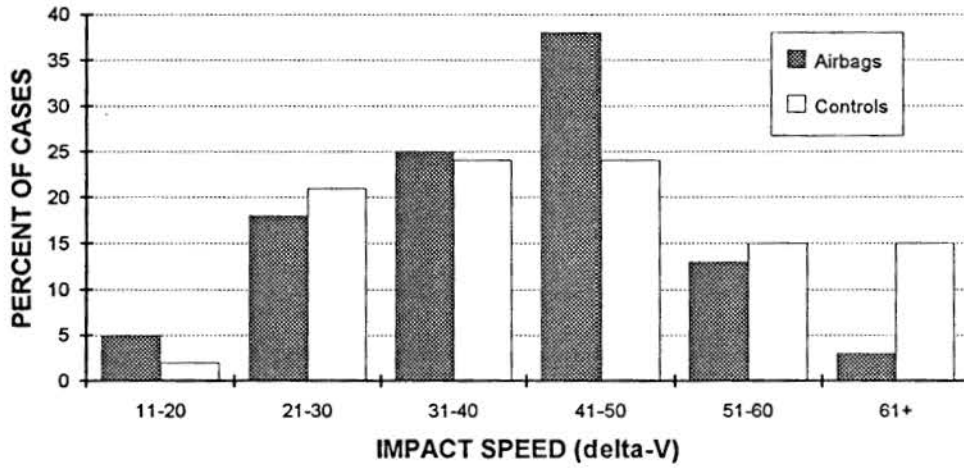


Figure 1 Delta-V distribution for airbag and control Commodores where change of velocity during impact could be calculated (69 percent of cases)

Table 1 - Percent of injuries to drivers of airbag and control Commodores involved in tow-away frontal crashes

Body Region Injured	Airbag Cases (n=63)			Non Airbag Controls (n=85)		
	All AIS	AIS 2+	AIS 3+	All AIS	AIS 2+	AIS 3+
Head	12.7%	4.8%	1.6%	14.1%	12.9%	2.4%
Face	15.9%	nil	nil	22.4%	2.4%	nil
Neck	23.8%	nil	nil	27.1%	3.5%	1.2%
Chest	25.4%	6.3%	1.6%	44.7%	14.1%	5.9%
Abdomen/pelvis	28.6%	nil	nil	30.6%	2.4%	2.4%
Spine	6.3%	3.2%	nil	2.4%	1.2%	nil
Upper extremity	54.0%	4.8%	nil	40.0%	7.1%	nil
Lower extremity	39.7%	4.8%	nil	32.9%	4.7%	nil

AIS scores range from 1 (minor) to 6 (untreatable). Multiple body regions included (MAIS per body region)

Table 2 - Mean Injury Severity Score (ISS), probability of injury and Harm sustained by drivers of airbag and non airbag control Commodores involved in tow-away frontal crashes

Body Region Injured	Number of cases	Mean ISS	Mean Harm (\$ 000s)	Probability of injury		
				AIS 2+	AIS 3+	ISS 15+
Airbag cases	63	2.6	9.2	0.19	0.03	0.02
No airbag controls	85	5.4	29.2	0.31	0.07	0.05

ISS is the sum of the 3 MAIS body region scores squared.

Table 3 - Sources of body region injuries to drivers of airbag and control Commodores

Source of Injury	Airbag Cases (n=63)		Non Airbag Controls (n=85)	
	All AIS	AIS 2+	All AIS	AIS 2+
Front screen & header	6.3%	nil	3.5%	1.2%
Steering assembly	15.9%	1.6%	21.2%	7.1%
Instrument panel	23.8%	3.2%	22.4%	3.5%
Side window & frame	3.2%	nil	2.4%	1.2%
B-pillar	nil	nil	1.2%	1.2%
Roof surface	4.8%	1.6%	nil	nil
Door and fittings	nil	nil	4.7%	1.2%
Floor & toepan	14.3%	4.8%	12.9%	2.4%
Seat belts	49.2%	7.9%	52.9%	11.8%
Airbag	14.3%	nil	nil	nil
Exterior contacts	nil	nil	1.2%	1.2%
Other & unknown	55.6%	4.8%	49.4%	10.6%

AIS scores range from 1 (minor) to 6 (untreatable). Multiple body regions included (MAIS per body region)

units for occupants of these Australian vehicles. The reduction in Harm for airbag occupants was around A\$20,000 per crash for crash severities up to 60km/h (the expected range for which airbags offer maximum protection).

In North America, Dalmotas (1995) compared the performance of restrained drivers in US airbag cars that crashed with a control sample of restrained but no airbag crashed vehicles. It should be noted that the Holden Commodore airbag is similar in size to US airbags, although has different firing thresholds and generally a lower, softer deployment rate. He found a reduction in severe head injuries (AIS 3+) of between 42% and 96%, depending on crash severity which is slightly better than the 33% reduction observed here, a difference that can probably be attributed to variations in seat belt design between the two countries. Involvement rates for these severe head injuries were similar in both studies (in the Canadian study, there were 1.3% serious head injuries for delta-V < 32km/h compared with the 1.6% severe head injury rate observed here for delta-Vs from 11 to 60km/h). However, Dalmotas (1995) reported some conflicting results with those found in this study. He noted a substantial increase in chest and abdominal injuries of AIS 3+ severity of over 250% among his airbag sample. In this study, there were reductions observed in both these body region injuries compared with control cases (73% fewer chest and no severe abdominal injuries). Unfortunately, it was not possible to segregate the low impact severity cases in the Canadian analysis. Dalmotas also reported a substantial increase in AIS 3+ upper extremity injuries for airbag deployed cases (an increase of between 8 and 90 times over that of his controls, depending on crash severity). This is also in contrast to the findings reported here; there were no cases of AIS 3+ upper extremity injuries reported for either airbag or control cases and for the AIS 2+ injuries, airbag occupants sustained 32% fewer upper extremity injuries than similar control cases.

These differences could be explained in one of two ways. First, it is not clear whether Dalmotas excluded high delta-V cases in which case most of his findings could be influenced by high speed impacts where the airbag may have less effect on injuries. Alternatively, as the US airbag is designed as a primary restraint unit, it is more aggressive than its Australian counterpart. As noted earlier, the Commodore airbag is designed as a secondary restraint system and has a firing threshold of around 28km/h (>17mph) and a less aggressive

deployment rate. The fewer severe chest, abdominal and upper extremity injuries, therefore, might be a reflection of a superior performance of the Australian unit. Given the importance of these findings for the design of optimal airbag protection, it is imperative to examine these results further with more cases than were available here. It could be that US airbags could offer significant improvements in occupant protection if they were redesigned as a secondary restraint mechanism and used in conjunction with seatbelts (higher firing thresholds and less aggressive deployment rates). For a limited number of cases investigated in the Commodore study where the airbag was fitted but not deployed (delta-V values up to 30km/h), there were no instances of occupants sustaining injury, which suggests that the Commodore firing threshold levels are not set too low.

While small in number, there were two thoracic fractures to the spine among these occupants compared to only one lower lumbar fracture in the control cases. Minor spinal injuries included bruising and abrasions. As it was difficult to assign source of injury to these, it is unclear what may have caused them. Unfortunately, there were no other results to compare this finding with (Dalmotas did not report on spinal injuries in his study). It would be important to continue to monitor these injuries in future.

There was a relatively modest 20% increase in lower limb injuries among airbag occupants, albeit of a minor nature. Dalmotas, too, reported an increase in severe pelvic and lower extremity injuries of 58% among airbag occupants. These findings suggest that there is scope for further improvements in lower limb protection in passenger cars involved in frontal crashes.

CONCLUSION

The results of this preliminary analysis are encouraging for occupants of Australian passenger cars. Although not all statistically significant, there were substantial benefits to occupants involved in frontal crashes in Holden Commodores in terms of reduced injuries (especially those of moderate to serious AIS 2+ severities) across the range of delta-Vs where airbags are expected to be of benefit. Spinal injuries among airbag occupants warrants further investigation. In general terms, the findings from this study compared favourably with similar studies overseas, suggesting that the supplementary designed airbag used in this popular Australian passenger car may be superior in performance

to its US primary restraint counterpart. There would seem to be considerable advantage internationally for extending this study to include many more cases to ensure that the findings reported here are robust.

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