

GEOMETRIC COMPATIBILITY IN NEAR SIDE IMPACT CRASHES.

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ABSTRACT

This paper investigates the issue of geometric incompatibility between vehicles involved in T-bone side impact crashes. Some illustrative examples and case histories are presented that clearly demonstrate how a bullet vehicle, with a high front bumper region and a raised bonnet with a very stiff fascia, intrudes significantly into the soft section of a sedan shaped car resulting in severe head and chest trauma.

Experimental results of two T-bone crash tests: a sedan car into a sedan car and a Four Wheel Drive (4WD) vehicle into a sedan car are described. The paper also presents a MADYMO simulation of a tram impacting the side of a car demonstrating how head strike of the struck vehicle's near side occupant can result in severe head injury at speeds as low as 35 km/h. The authors conclude with some discussion of how the front of vehicles should be designed so as to eliminate the possibility of severe intrusion and head strike in such crashes.

INTRODUCTION

Debate regarding vehicle compatibility has emerged in an attempt to further reduce vehicle fatalities and injuries. However, the main focus seems to be on the issue of mass differential. While mass certainly plays a role in whether a person is injured or not, it plays a smaller role in comparison to the issue of geometric compatibility between vehicles [Reznitzer and Grzebieta 1999, Grzebieta and Reznitzer 2000b].

The technology to design crashworthy vehicles has advanced considerably over the past decade. The use of "Real World" data feedback, sophisticated crash testing and computer simulation technology is accepted in the development of new sedan cars. However, the techniques used for designing the front profile of heavier vehicles and trucks to be less aggressive when impacting a car do not seem to be filtering through. Whilst mass is an issue with respect to survivability in crashes, the authors are finding good vehicle geometry is the key factor to developing a heavy vehicle that is

crash compatible with the average car fleet. Massive head and chest injuries to the occupants of a car impacted by a heavy vehicle are common. A mass difference between the two vehicles is often blamed for such injuries. However, in a large number of cases incompatible heavy vehicle geometry has often led to an avoidable fatality [Reznitzer 1993, Reznitzer and Foong 1991]. This is because the design requirements do not include the whole system or environment where the heavy vehicle needs to operate in. This seems to be more so for public infrastructure transport.

Crashworthiness compatibility has been placed in the "too hard" basket and ignored or addressed in a piecemeal fashion in response to public outcry. The authors are not aware of any standards governing the front profiles of heavy vehicles in regards to their crashworthiness during a T bone impact. The onus for occupant protection seems to be focussed entirely on sedan car manufacturers. This is despite the fact that simulation methods are available that can readily analyse such crashes and a crash test procedure could be easily developed that would require mitigating injuries in such crashes [Zou, Reznitzer and Grzebieta 2001].

INTERFACE COMPATIBILITY

Crashes involving heavy vehicles (trucks, semi-trailers, trams, buses) and other road users have resulted in over 4000 fatalities in Australia in the last 10 years [Reznitzer (1993)] with the statistics clearly identifying the over-representation of this vehicle type (particularly semi-trailers) in fatal and serious injury crashes. Over 80% of the victims in these crashes are the other road user. The above study and others in the USA and Europe have identified that the major factor in this significant over-involvement is the incompatible and aggressive design of heavy vehicles, a feature aggravated by the significant mass difference. These studies have identified that the front, side and rear design of heavy vehicles can be effectively modified to significantly reduce the harm potential of heavy vehicle crashes.

A major design feature of heavy vehicles identified as significantly increasing the injury risk to pedestrians, cyclists and vehicle occupants, is the high stiffness and aggressiveness of their front structures. A common feature is the raised bumper region and the steel front surface. Similarly the use of heavy bullbars on the front of heavy vehicles as shown in Figure 1 and also

typically on four wheel drive vehicles further exacerbates crash severity. These designs because of their high stiffness, unyielding characteristics (not energy absorbing) and small contact areas are the antitheses of designs aimed at reducing injury risk.

Figure 1 shows that the height of the truck's main bumper region and bull bar is well above the vehicle's sill and floor pan. Intrusion into the softer part of the car's side is significant. Moreover the occupant's head often strikes the hard front surface of a bull bar's cross bar or the truck face in a manner somewhat similar to head strike in a side impact pole or tree crash.

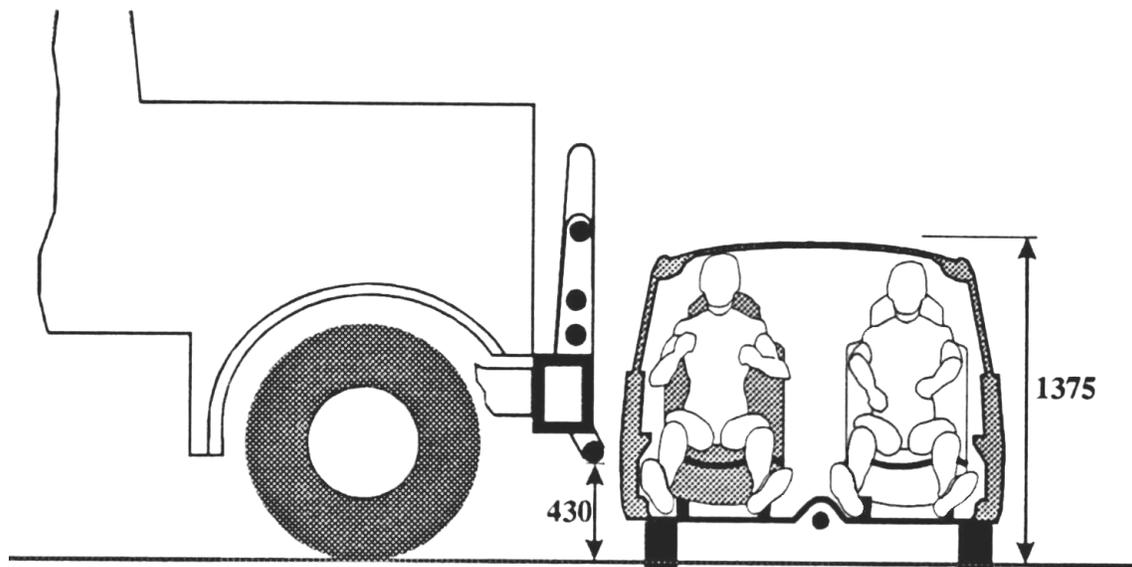


Figure 1 Incompatibility between heavy vehicles and other road users. Photo shows heavy vehicle crash with the side of car where driver was killed. Sketch shows truck-car interaction where over ride and head contact with bull bar occurs.

Trams and buses

Figure 2 shows how aggressive the front of a tram can be in a low speed crash. Both trams and buses are designed as stiff, unyielding structures that also put the other road users at considerable increased risk of severe injuries in crashes. The gap below the tram's steel bumper is clearly visible. The front of a B class tram in Melbourne was compared to the sides of different cars by Grzebieta and Rechnitzer (2000). They found that the tram's bumper region misses the most structurally sound part of most cars. Instead of pushing the car, the aggressive front end intrudes into the car's relatively soft occupant compartment just below the window, over-running the car's base sill or rocker panel which is at an average height of just under 300 mm.

A computer simulation study carried out at Monash has shown that a side impact crash of a tram into a car will result in a fatality at speeds of as low as 35 kilometres per hour. The study also showed that a tram with a geometrically compatible crash interface and soft facia will reduced injuries to minor levels. The same situation applies to busses.

Figure 3 shows a MADYMO model of a tram impacting a car with an occupant developed by the authors. Head strike of the occupant with the very stiff steel front facia is clearly visible. When an over-ride barrier and a soft face was introduced into the model the head and chest injuries dropped dramatically to survivable levels.

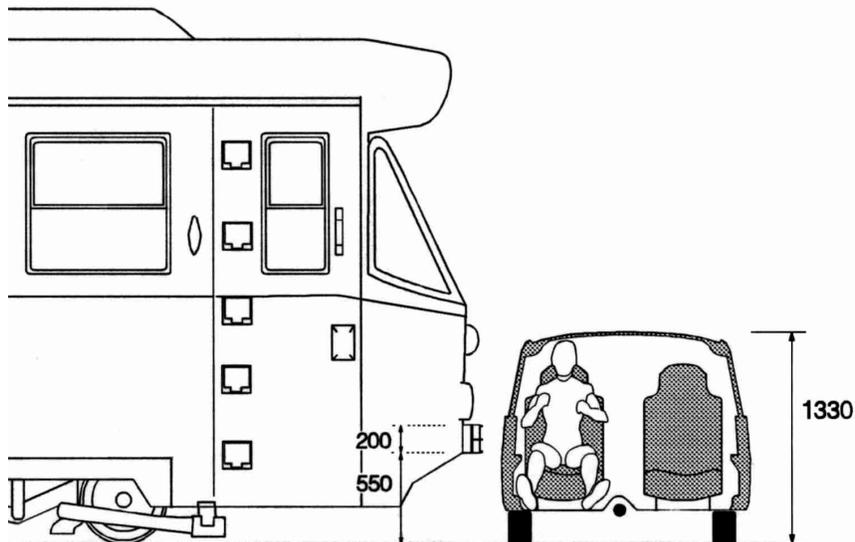


Figure 2 Side impact crash of a 'B' class tram into a car. Lower sketch shows cross section through car and tram indicating position of front steel bumper relative to side of car and driver's seating position.

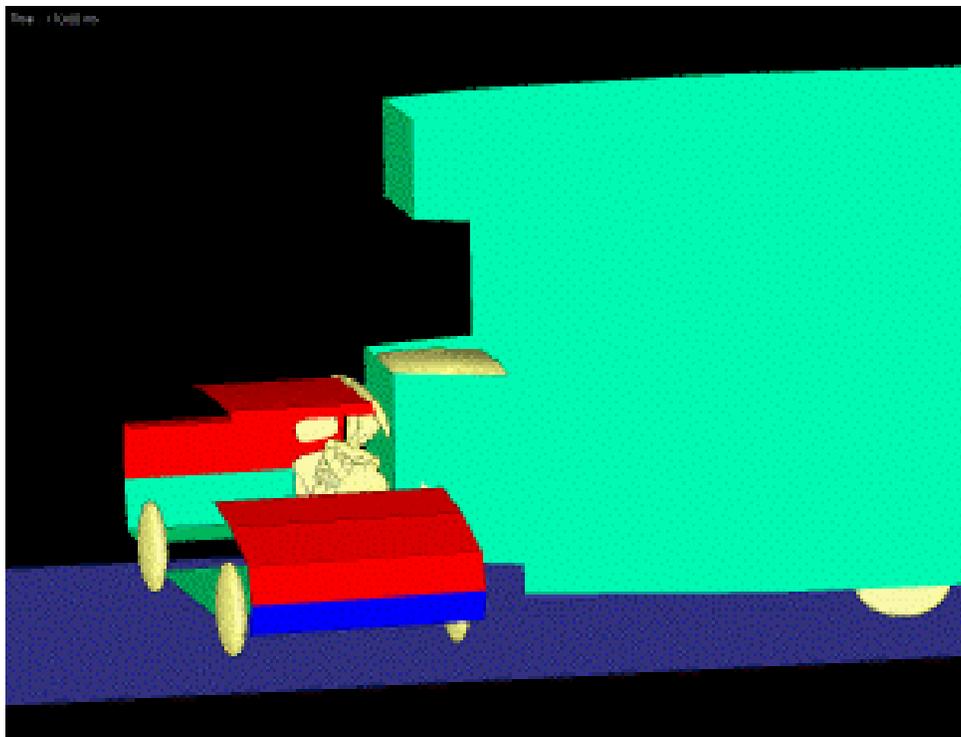


Figure 3 MADYMO model of tram into car with occupant. Note the head contact with the front fascia of the tram through the car window.

Four wheel drive vehicles

Four wheel drive (4WD) vehicles are now proliferating our urban streets. These vehicles are similar in size to the pickup trucks and large urban vans in the USA. Once used predominantly in rural areas for difficult access over rugged terrains, 4WDs are now being marketed as the ultimate “get away” vehicle in Australia and status symbol of wealth. They have a mass and height advantage that bias the outcome for the 4WD occupants when manoeuvring through traffic and when involved in crashes with lighter sedan cars. However 4WDs significantly jeopardise the safety of other road users, increasing the injury risk to pedestrians, cyclists and sedan vehicle occupants, because of the aggressiveness of their front structure.

Two crash tests were carried out by Monash University and Folksam Insurance at Autoliv Australia, to demonstrate the incompatible characteristic of a 4WD in side impact crashes. The first crash test involved a 4WD vehicle crashing into the side of a sedan vehicle as indicated in Figure 4. The mass of the 4WD was 1536 kg being a little more than the mass of the sedan vehicle at 1380 kgs. A SID dummy with a Hybrid III neck was used for the driver for both crash tests.

Figure 4 shows the bottom of the 4WD bumper is around 300 mm above the car’s structural sill and the top of the engine bonnet is at shoulder height of the car driver dummy.

A second test of a sedan car into a sedan car side impact was also carried out at 52 km/hr for comparative purposes. The same make of sedan cars were used as the target vehicle in Figure 4. Figures 5 and 6 show the crash sequence. It is clear from the film footage that the dummies head rotates sideways towards the bullet vehicle’s bonnet. However, high speed video revealed that no head contact occurs despite the head moving well outside the window line (Figure 6). In this case HIC36 was 352 and the TTI was 47 being much less than the injury thresholds of 1000 (HIC) and 85 (TTI), i.e. they were minor despite significant head movement through the window during the crash.

In the case of the 4WD into the sedan (Figure 4), head strike with the bonnet fascia of the bullet vehicle occurs and is clearly visible in the high speed cinematography. Figure 7 shows images of the crash sequence extracted from the film footage. The photo in Figure 8 shows the moment of impact where the car driver’s head hits the top of the 4WD’s engine bonnet. The speed of impact

was 52 km/h and the resulting HIC36 for the dummy was 1456 and the TTI was 182, being clearly well over injury criteria thresholds. The damage to the struck vehicle was significant with intrusion at around 500-600 mm as shown in Figure 9 whereas damage to the 4WD bullet vehicle was in stark contrast minor as can be clearly seen in Figure 10. However, a dent remained in the 4WD bonnet from the car driver's head as shown in the inset enlargement. Over-ride of the sill of the target car was clearly evident and the 4WD did not seem to engage either the A or C pillar.

Had the top of the 4WD vehicle's front bonnet been profiled back away reducing its bull nose shape, head contact would have been avoided and hence injuries reduced significantly similar to the sedan into sedan result. The Monash crash tests show that head contact during a side impact crash is an important factor that is rarely considered in the design of 4WD vehicles or for that matter any heavy vehicle design. This same injury mechanism occurs in tram impacts and in truck impacts as discussed previously.

While the introduction of side airbags into cars may help reduce the severity of such crashes, bad geometry design of the bullet vehicle's front where over-ride can occur, completely negates any benefits of such systems.

DISCUSSION AND CONCLUSIONS

The main conclusion from this paper is that in a T-bone near side impact crash the driver's head will whip sideways and protrude well outside the window line. If the bullet vehicle's front fascia is at shoulder level or higher, head strike will occur. If the front fascia is made from a hard material, i.e. steel, serious head injuries will occur at quite low impact speeds.

A second conclusion is that bullet vehicle's front profile geometry and then its stiffness are the two main factors, in that order, that govern survivability in T-bone crashes.

To reduce the number of vehicle fatalities there must be a paradigm shift in thinking in regards to the crashworthiness design of the whole transport system



Figure 4 Photo of 4WD vehicle showing height of bumper region compared to sedan and occupant dummy prior to crash test.

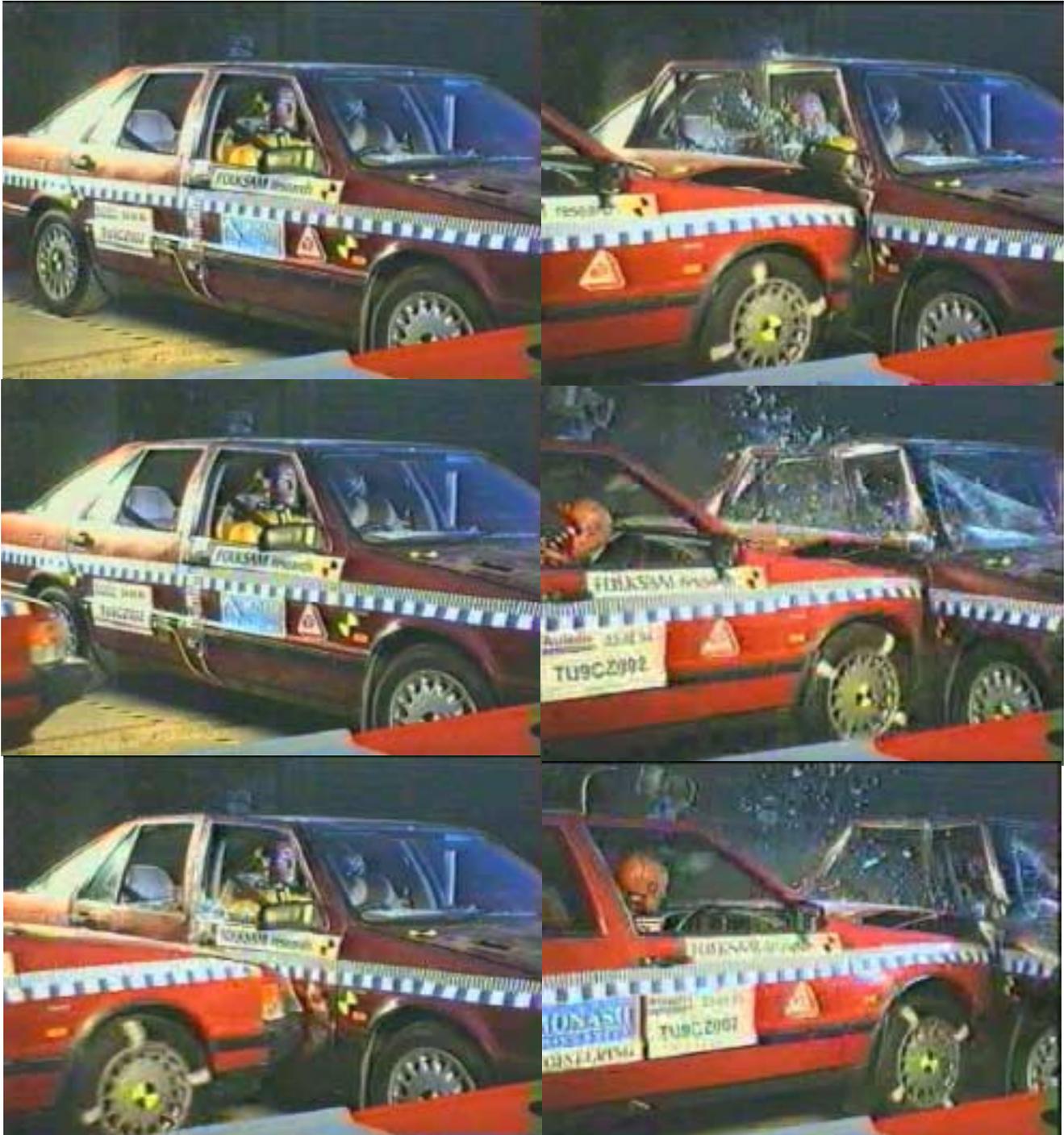


Figure 5 VHS video sequence of medium size sedan car into sedan car (T bone) side impact crash. Note driver's head in target vehicle comes out of window. Figure 6 shows this mechanism at slower time steps.



Figure 6 High speed video footage of car into car (T Bone) side impact shown in Figure 5, showing how driver's head of hit car is thrown out of the window and almost touches the bonnet (hood) of the incoming bullet vehicle.



Figure 7 High speed CINE footage of car into car T Bone side impact viewed from 4WD roof and shown in Figure 5. Note how driver's head of hit car is thrown out of the window and impacts the bonnet (hood) of the incoming bullet vehicle (see also Figure 8).

rather than individual sub-components such as a sedan vehicle. No longer can the car and occupants be considered as an isolated system crash tested in a pristine laboratory environment in accordance to a certification procedure that in some cases bears little relationship with reality.

Likewise manufacturers of heavy vehicles, four wheel drive vehicles, pickup trucks, urban vans, etc. have had little restrictions on how they must design their vehicles to be compatible with other road users in the event of a

crash. The examples presented in this paper clearly demonstrate that these vehicles are overly aggressive in T bone type side impact crashes.

Car, heavy vehicles and occupants are in fact subsystems of the whole road environment and interact with other large and small vehicles as well as road furniture. Thus the environment in which a vehicle is driven as well as the vehicle must be designed to be tolerant of an accident and must therefore be designed to be compatible, both from a geometric and stiffness perspective, with all road users in the case of a crash.

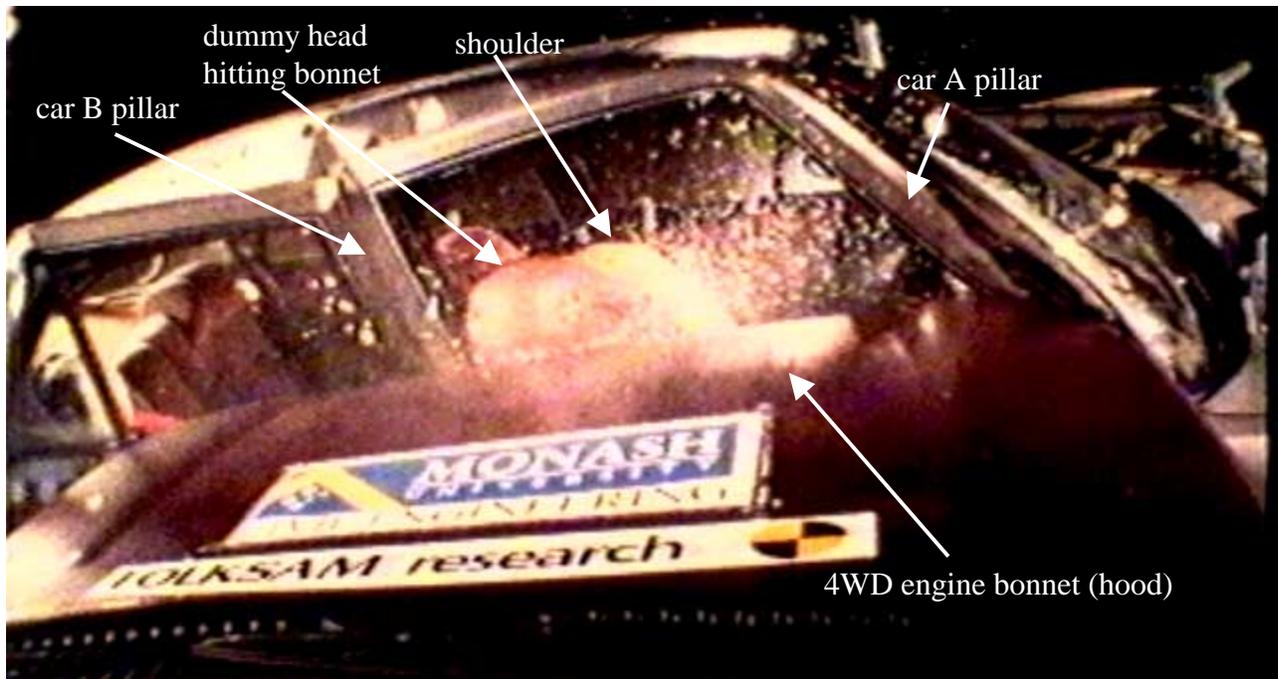


Figure 8 View from roof of 4WD vehicle towards front during crash into a sedan vehicle. Photo shows head of car driver dummy striking top of 4WD bonnet (hood). See also Figure 10.

Similarly crash testing certification needs to more closely reflect the real behaviour of any new product (vehicle, truck, road furniture, etc.) and its effect on the total transport system, i.e. the new product's crashworthiness performance across a range of crash scenarios and interactions must be assessed.

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Figure 9 Target car after impact by 4WD vehicle shown in Figure 10 below. Note considerable intrusion where C and A pillars have not been engaged in the crash.

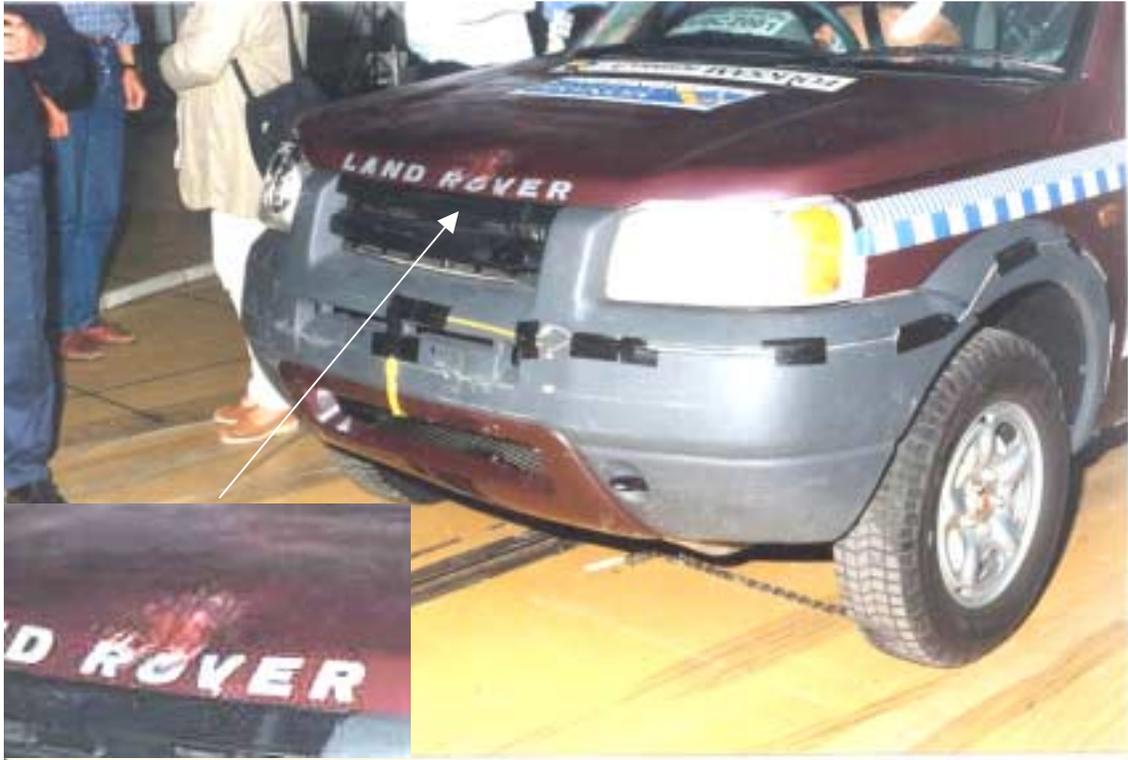


Figure 10 showing minor damage only to 4WD bullet vehicle. Note dent on bonnet caused by dummy head strike in inset enlargement.