SOME OBSERVATIONS ON THE RECONSTRUCTION OF A SIDE IMPACT ACCIDENT

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1 - ABSTRACT

This paper discusses some aspects of three reproductions of a real world side impact of a British Leyland Mini, in which the unrestrained driver received OAIS 4 injuries.

The use of Part 572 and TRRL Side Impact dummies allows comparisons to be made between the outputs of these two surrogates and the actual occupant's injuries. The differences in the kinematics are discussed, and in particular the movements of the dummies' heads are compared with those of cadavers reported elsewhere. Problems encountered with the setting up of the vehicles are highlighted, and the usefulness of the CRASH program is illustrated, together with some reservations as to its use in accident reconstructions.

2 - INTRODUCTION

The way in which vehicles and dummies perform under standard impact conditions is now quite widely known. However, the field performance of safety related items is not so well understood and is the object of continuing research at many organisations throughout the world. Similarly, the correlation of the injuries received by occupants in real accidents with the forces and accelerations measured by dummies in test collisions is by no means agreed.

A technique which has been used in the past to determine the injury threshold levels for specific parts of the human frame is the replication by test devices of the deformations of the vehicle produced by occupants in real accidents. The occupants' injuries and the associated forces on the test devices give a correlation with the forces to which the real occupants were subjected (1)*. A similar method for determining the injury tolerances for

*Numbers in parentheses designate references at the end of the paper.

restrained subjects has also been employed, where the forces acting on restrained dummies in sled tests have been correlated with human injury, and the probability of human injury, where the actual injury data are derived from samples of field accidents (2 and 3).

A further refinement of this method is the reproduction of field accidents using dummies or cadavers to simulate the occupants and using whole vehicles in controlled collisions as similar as possible to the actual accident. The injuries to the real occupants can then be correlated with the dummies' loadings or accelerations or with the cadavers' injuries. However, for such a technique to provide usable data, a series of reproductions of several accidents must be undertaken to take account of the spread of data which arises because of the inherent differences in human tolerance (for example, differences due to age) and also because of dummy inconsistencies and variations in the accident reconstructions.

Further complications are presented by the limited biokinetic fidelity of present-day dummies. In particular, doubts have been raised regarding the accuracy with which current dummies represent human head movements in side impacts.

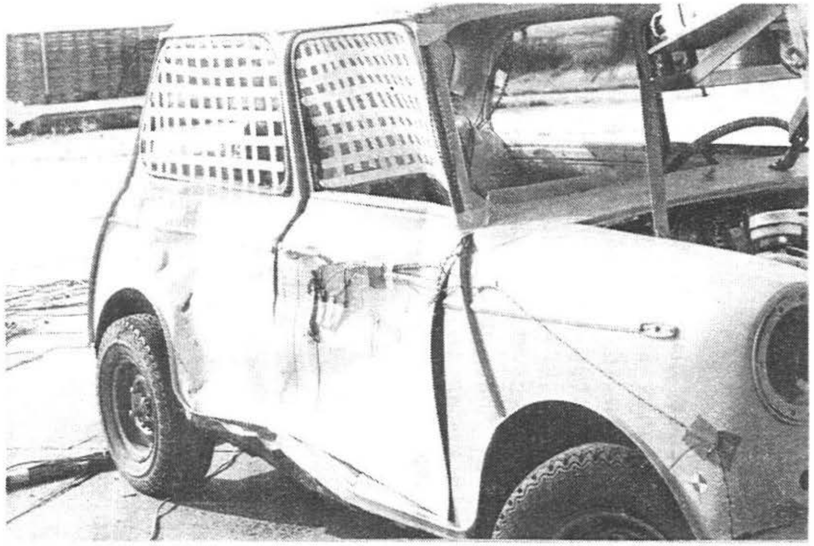
This paper raises several problems which have been encountered after partial completion of one such whole-vehicle reproduction programme. The work is to continue with the actual occupant being replaced by a cadaver in a further test.

3 - THE REAL ACCIDENT

The accident occurred at a signal controlled cross-roads, to the east of Birmingham's centre. The damage to the struck car is shown in photograph 1. The Mini, which was less than a year old, was struck directly on the driver's door and rear panel, with a direction of force between 3 and 4 o'clock. The centre of the impact was 16 cm forward of the rear edge of the door, and clear imprints of the Vauxhall Victor's headlights and bumper were left on the Mini's panelling, the imprint being 55 cm from ground level and causing the maximum deformation of the exterior panels of 32 cm. The direct loading extended for a distance of approximately 120 cm. This partially crushed the sidewall, and caused a maximum intrusion into the passenger compartment of 25½ cm. The struck side wheelbase was reduced by 3 cm.

The striking car was a three year old Vauxhall Victor which suffered a frontal impact with a direction of force of 11 o'clock. There was 11 cm of crush on the nearside and 12 cm on the offside. The damage was entirely confined to the front body panels, there being no movement of the A pillars and no passenger compartment intrusion. The unrestrained driver of the striking car was not injured.

Photograph 1 Damage to Accident Target



Photograph 2 Damage to Target in Test 1

Photograph 3 Damage to Target in Test 2

Photograph 4 Damage to Target in Test 3

The sole occupant of the Mini was a 36 year old unbelted male. He received the following injuries:

Concussion, without skull fracture:	AIS 2	(4)
Lacerations to right side of scalp:	AIS 1	
Fracture to ribs 3-9 on the right side with overlapping flail chest:	AIS 4	
Crack fracture of the right ilium:	AIS 2	

The head injuries were due to contacts with the side window and B pillar, and the chest and pelvic fractures were from contacts on the intruding door. The occupant was detained in hospital for 30 days, was on a ventilator for three weeks, but subsequently recovered. His OAIS was 4 and ISS was 24 (5).

No skid marks from either car were apparent after the accident, and a scaled site plan was not drawn by the police officers dealing with the case. This made accident reconstruction difficult, and in particular, no accurate vehicle speed estimates could be made.

4 - THE ACCIDENT REPRODUCTIONS

Several factors of the accident lent themselves to further study by the means of accident reproduction:-

a) the severity of the driver's chest injuries which were near to the threshold of critical injury,

b) the use of the TRRL Side Impact Dummy (6), a comparison of its responses with the actual injuries suffered, and with the information provided by a Part 572 dummy. More and more test work and real accident investigation is turning to a consideration of side impacts, because of the relative success in reducing occupant injuries in frontal impacts, particularly where a restraint system is employed (7, 8, 9). This recent interest in the safety performance of the side structures of cars has led to a need for the development of a dummy which would display kinematic properties in side impacts similar to those of real accident victims.

c) as more and more analyses of field accidents involve the computer program CRASH to provide collision speeds, ΔV etc., accident reproductions provide a useful check on the program's ability to determine accurate and reliable collision parameters.

It was apparent from the damage to the accident Mini that it was moving only slowly at the time of the accident. The occupant's contacts indicated a trajectory at right angles to the vehicle's long axis. It was decided, therefore, that the tests would be run with the struck Mini stationary and the bullet vehicle travelling perpendicularly towards it.

Because of the unavailability of a Vauxhall FD Victor (which ceased production in 1972) a Mark II Marina was chosen to be the bullet vehicle. In an attempt to duplicate the clear bumper line indented on the Mini (shown in photograph 1) the Marina's bumper was raised on brackets to a height which corresponded to that of the Vauxhall's bumper at impact. It was not thought that the front end crush characteristics of the Marina would be substantially different from those of an FD Victor, particularly at the fairly low Δv to which it would be subjected. However, in retrospect, the different bullet vehicle was seen to be a possible source of error.

To satisfy the requirements outlined above, three crash tests were conducted, with the view that further tests may be made in the future replacing the dummies with cadavers, so as to provide a larger base of 'injury' test data.

It was decided to conduct an initial 25 kph test to determine base line data. The second reproduction was to be an attempt to reproduce the damage to the accident Mini, and then, if the attempt was an accurate one (in terms of vehicle deformation), a further test at the same speed was to be run. The driver was the only occupant of the real accident Mini, but in the crash tests the struck-side front seat occupant (simulating the driver, who had no interaction with the steering wheel) was supplemented with a struck-side rear seat occupant. The use of dummies in the rear of each struck car allowed for extra pairs of comparisons to be made, even though these data could not be compared with any real 'victim' injuries.

Some non-structural items of the Minis were removed to maintain the all-up weight of the vehicles to be close to that of the real accident vehicle. Similarly sufficient weights were added to the Marina bullet cars to ensure that their mass was as close as possible to that of the real accident Vauxhall. Thus the mass ratio of the vehicles in the simulated accident was the same as that in the actual accident, approximately 0.6:1 (Mini:Marina).

4.1 Test 1

As intended, the Marina bullet car was run into the Mini target at a speed of 25.4 kph. The damage to the struck car is shown in photograph 2 and the damage profile is shown in figure 1. As can be seen, the extent of the damage is less than that of the real accident car.

A summary of the dummies' loadings is shown in table 1, together with similar data from the other tests.

For test 1, the centre line of the bullet was 15.2 cm rearwards of its intended position, thus producing some rotation of the vehicles after approximately 60 ms - this had little or no effect on dummy responses, since initial dummy contacts were around 40 ms. (The centre of the impact was 51 cm rearwards of the Mini's centre of gravity).

4.2 Test 2

From the results obtained from the first test, it was thought that a collision speed of 45 kph for the second test would be likely to reproduce the damage sustained by the Mini in the real accident. The actual test impact speed was 47.3 kph. Immediately after the impact the target vehicle spun clockwise through almost 90^{o} and both vehicles rolled approximately 19 metres in

Figure 1 Damage Profiles in the 3 Tests

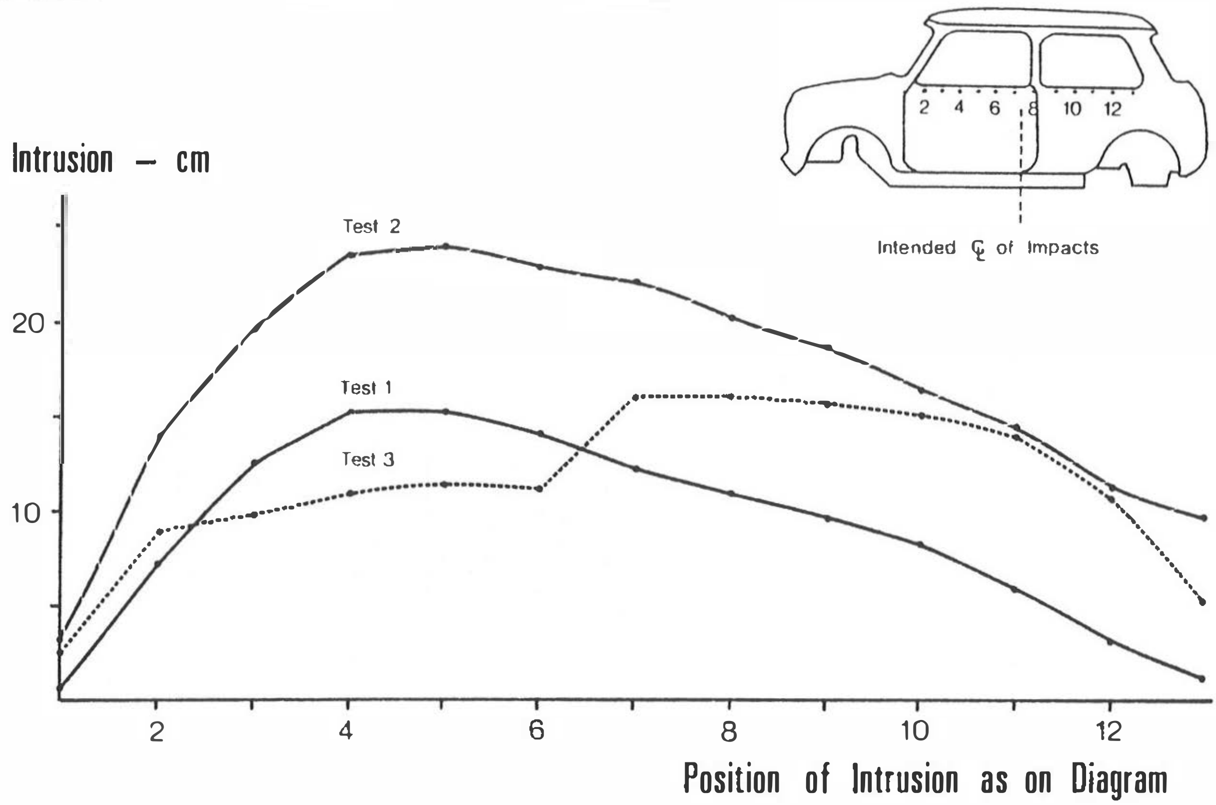
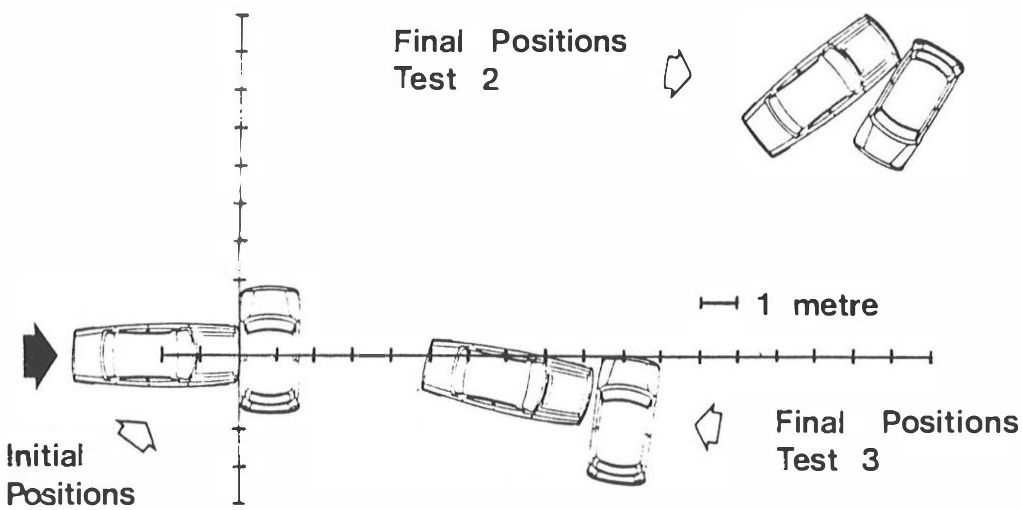
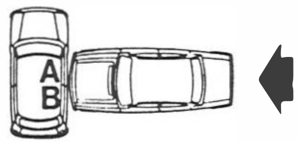


Figure 2 Final Positions of the Vehicles in Tests 2 and 3



In test 2 the target was struck on its right side, and in test 3 on its left side.

Table 1 Summary of Occupant Injuries and Test Results



RESULTS	ACTUAL ACCIDENT	TEST 1		TEST 2		TEST 3		TOLERANCE LEVELS	
BULLET IMPACT VELOCITY (kph) ΔV (kph)*	N/K N/K	25.4 9.0		47.3 16.7		45.5 18.5			
TARGET ΔV (kph)* MAX DEFORMATION - INSIDE (cm) - OUTSIDE (cm)	N/K 25.5 32.0	15.8 15.3 25.0		31.3 22.8 31.0		28.4 16.3 21.0			
OCCUPANT DATA	A	A	B	A	B	A	B		
DUMMY TYPE	36 yrs, Male, 178cm, 70kg	TRRL	PART 572	TRRL	PART 572	PART 572	TRRL	TRRL	PART 572
HEAD HIC a max/a 3 ms (g) HEAD/VEHICLE CONTACT	Concussion & laceration from impact on window/B pillar - AIS 2	92 44/37 YES	112 51/43 YES	293 95/72 YES	225 42/40 NO	130 41/39 YES	782 141/106 YES	1000 -/80 -	1000 -/80 -
THORAX SEVERITY INDEX a max/a 3 ms (g) MAX VELOCITY (kph)	Fracture of 3 - 9 ribs right with flail chest from door top - AIS 4	112 59/49 19.4	83 34/30 21.6	352 87/61 36.0	247 67/53 40.0	239 61/55 33.0	264 67/61 38.5	1000 -/60 -	1000 -/60 -
PELVIS SEVERITY INDEX a max/a 3 ms (g) MAX VELOCITY (kph)	Crack fracture of right ilium from door contact - AIS 2	96 38/35 20.5	65 32/30 28.0	1226 158/140 38.6	426 101/70 36.8	203 54/48 32.5	223 64/55 36.0	1000 -/60 -	1000 -/60 -
MAX SHOULDER (kN) CONTACT TIME (ms)		8.47 30	- 33	8.52 19	- 23	- 12	0.58 -	7 -	
MAX RIB 1 LOAD (kN) RIB 2 RIB 3 RIB 4		0.56 1.04 0.76 1.73	- - - -	1.99 2.06 1.53 2.45	- - - -	- - - -	2.41 2.38 0.46 0.73	1 1 1 1	
MAX ILIAC CREST (kN) MAX HIP LOAD (kN)		3.38 N/K	- -	4.62 2.85	- -	- -	5.32 0.25	{6	

*MEASURED AT THE BASE OF THE B PILLAR, ON THE NON-STRUCK SIDE FOR THE TARGET VEHICLES.

a curved trajectory, from the site of the impact. The final positions of the vehicles in both high speed tests are shown in figure 2. The impact centre line was 6.4 cm rearwards of the intended position, and hence 42 cm rearwards of the centre of gravity.

The extent of the vehicle damage (photograph 3) is similar to that of the real accident target, but the pattern of damage is rather different. This is perhaps due to some forward velocity of the struck car in the real accident, which displaced the 'B' pillar rearwards, thus pulling the roofline down further than would have been the case in a purely transverse collision.

The distinctive line caused by the Vauxhall's bumper was not replicated by the Marina's bumper in any of the tests. It is thought that the strength of the brackets used to raise the height of the bumper on the Marinas was not great enough to transfer the collision forces without deformation, thereby allowing the front panels and grill of the bullets to directly load the Mini's side panels.

It is of interest to note that although the change in velocity (ΔV) for the struck Mini was 31.3 kph, the maximum velocities for the thoracic and pelvic parts of the dummies were 36.0 and 38.6 kph for SID and 40.0 and 36.8 kph for the rear Part 572 dummy, an illustration of the fact that occupants can be accelerated to speeds higher than the struck vehicle's maximum speed (10).

4.3 Test 3

Because of the similarity of the damage to the target vehicle and to the accident vehicle, it was decided to repeat the test with the same impact conditions, except that the positions of the SID and the Part 572 dummy in the struck car were reversed. This allowed comparisons between both dummy readings in both seating positions, and also with the injuries to the front seat occupant of the car involved in the real accident.

The measured impact speed of the bullet car was 45.5 kph. The centre line of the bullet vehicle was 7 cm forward of the intended site and very little rotation of the vehicles occurred (see figure 2). Intrusion into the passenger compartment was considerably less than that of the second test, and at the front seat reference point, less even than the intrusion suffered in the first test at 25.4 kph. The vehicle damage is shown in photograph 4.

5 - DISCUSSION

The intention of this paper is not to present the results of the three crash tests outlined above, but to point out several facets of the work which should be noted by those doing similar work in the future. It is realised that the comments made are based on the results of three tests only, but they are nevertheless of interest, particularly in the light of the development of future standards relating to the side impact collision, where a new test procedure and perhaps new dummies may be demanded.

5.1 The Need for Accurate Vehicle Alignment

In each case the Marina bullet car's centre line was set-up adjacent to the intended impact centre line on the Mini target. Care was taken to ensure that the vehicles were not moved after this setting up, except to return the bullet to the position where it was connected to its accelerator. The positions of the actual impact centre lines have been mentioned above, i.e. -15.2, -6.4 and +7.0 cm from the intended centre line, a range of 22.2 cm. In test 2 the target car rotated through about 90^{o}, allowing both vehicles to roll together to their final resting position. The more forward location of the centre of impact in test three produced little rotation of the bullet car (the vehicles' centres of gravity being nearer the impact centre line) and the vehicles came to rest almost normal to each other after travelling about 10 metres, compared with about 19 metres for test 2.

Secondly, the difference in the pattern of passenger compartment intrusion in the two high speed tests (figure 1) reflects the difference in collision conditions. The difference in impact speed was responsible for a reduction in kinetic energy of only 7.5%, but the intrusion in the third test was at all locations less than that of the second test, and forward of the B pillar intrusion was approximately halved. The more forward location of the impact centre line in test 3 resulted in the relatively strong A pillar of the target being directly contacted by the stiff sections of the bullet - this was not the case in the other tests.

The significant conclusion from this is that a fairly small difference in vehicle positioning can have quite marked effects on the resultant intrusion in a side impact test, where the difference in position introduces the involvement of a stiff member. In vehicle testing the involvement of the sill can also greatly affect the damage pattern, and a test where the sill is included in the contacted part of the car (the side impact section of FMVSS 208 for example) could well be very different from a real world collision, where frequently the sill is undamaged if the struck car is hit by another vehicle, the bumper of which is considerably higher than the floor of the struck car.

5.2 Dummy Responses

Data have already been presented in table 1 which summarises the dummies' responses to impact in the 3 tests outlined above. It is readily seen that in some instances, the loads and accelerations suffered by the dummies are not in agreement with the currently accepted tolerance levels, when the injuries in the actual accident are considered. However, it is not possible to conclude from this that the tolerance levels are incorrect, but merely that some of the data points presented here do not confirm those levels.

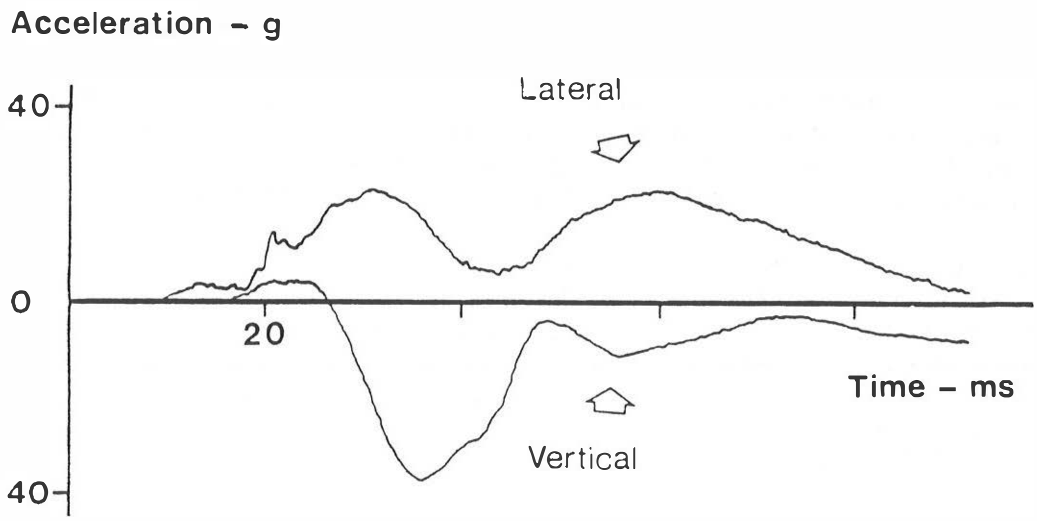
For example, in test 2 the SID was subjected to loads exceeding the tolerance level for its shoulder, while in the real accident the occupant received no corresponding injury. This discrepancy may be due to different loads imposed by the non-similar bullet cars, or it may represent a tolerance level which is too low. Alternatively, the real occupant may have had an exceptionally strong skeleton. However, differences in the nature of SID and Part 572 shoulder behaviour under impact, when compared with cadavers have been noted elsewhere (11). In that work it was apparent that the cadaver's shoulder and humerus folded away from the impact (with a solid wall) while the dummies' shoulders remained rigid and did not rotate in the same way. It may be that the shoulders of real accident victims do not transmit major forces transversely to the rib cage, and so escape injury.

In contrast, the combined maximum iliac crest and hip load of 7.47 kN for SID in the same test may reflect a realistic tolerance level, since the accident occupant suffered a crack fracture of the right ilium from a contact with the door. Similarly, the proposed pelvis severity index of 1000 would not appear to be contradicted.

In addition to the comments made above concerning the apparent lack of realistic representation of the human shoulder joint by current dummies, the trajectories of the dummies' heads in the side impacts deserve attention. The head and neck of SID are of standard design and comply with sections 6 and 7 of Part 572 of the Code of Federal Regulations. Table 1 shows that for the front seat occupants of the high speed tests the dummies' head data are not consistent with the injuries suffered by the occupant of the actual accident. Analysis of the films of the test shows that the contact made on the B pillar of the target car in the last test was of a glancing nature and the evidence of contact on the vehicle confirmed this.

This fact is an indication that the shoulder, neck and head structures of SID and Part 572 are probably not allowing the dummy to accurately replicate the motions of a human being's head in a side impact. In the case of a dummy impact the rigid shoulder holds the base of the neck away from the impact area, thus allowing the head to rotate, and so a glancing blow is produced to the top of the head. This is illustrated by the fact that the lateral component of the resultant head accelerations is smaller than the vertical component as measured by the accelerometers (figure 3). The lack of an arm structure on SID reduces the effect somewhat, but the problem is still a dominant one. Cadavers, on the other hand, do not undergo such rotation, and the head tends to strike a flat surface with its parietal and temporal bones, which would produce a relatively high lateral component of the acceleration.

Figure 3 Head Accelerations for Front Seat Part 572 Dummy in Test 3



The following peak head accelerations were found by Melvin et al (11) when cadavers and dummies were projected against a rigid wall at 33 kph to simulate a side impact.

Table 2 Peak Head Accelerations in 33 kph Side Impacts with a Wall (after Melvin et al)

	Peak Head Acceleration (g)		
Subject Test No	Cadaver (010)	Part 572 (014)	TRRL SID (017)
Longitudinal	57	23	25
Vertical	174	85	157
Transverse	293	41	197

For the cadaver the dominant component is a transverse one, while for the Part 572 dummy the largest acceleration is in the vertical direction. For SID the transverse peak is the greatest, but there is still a large vertical component. It appears from this that SID provides better replication of cadaver response.

However, the work of Ewing et al (12) with fully restrained volunteers suggests that, at least at low levels of acceleration (nominally 2-11g) much of the head motion in a side impact is rotational, after a small initial translation. It is important that this apparent contradiction in head trajectories be resolved, perhaps by field accident studies which accurately position the site of contact on the head.

In test 3, the rear seat SID's shoulder did not contact the intruding side panel, but simply passed over the waist rail. The separation of the window glass from the rail ensured that the shoulder did not even contact the glass with any severity, receiving a load of only 0.58kN. The glass remained unbroken. The head was thus allowed to translate more than in other tests, and it received a contact of a severity more likely to be indicative of the one that the real occupant suffered. The evidence of the contact on the vehicle was more like a real accident head contact than any of the others.

The high vertical peaks in SID may not in fact be due to direct head loading but a force transfer through the dummy's neck. In the two tests where SID was in the front of the target car, the head resultant acceleration showed two pronounced peaks which, from film analysis, occurred before the head struck the vehicles' B pillars. The shoulder and thorax traces indicate that these head peaks may in fact be due to shoulder and thorax accelerations being transmitted through the dummy's neck to the head accelerometers, these peaks occurring some 20 ms before the head contact in the high speed test. In the vertical direction the neck has poor compliance when loaded in tension.

5.3 CRASH Program

The computer program 'CRASH' has been developed to enable a useful measure of crash severity to be calculated from data that is readily available to the accident investigator. While several levels of sophistication of the input data are usable, the most accurate simulation is found when complete scene and vehicle damage data are utilised. The program is presented in an interactive form which can be dealt with by a fairly unskilled operator, but the result is only as reliable and accurate as the data input.

The procedure is now in quite wide use as a method of calculating ΔV. For example, Monk et al (13) describe its use in an analysis of 221 car-to-car side impacts from MDAI files. A total of 259 cases met the side impact criteria, but 35 were rejected because of a lack of data. Forty-eight cases contained data sufficient for a 'high-level' trajectory reconstruction, while the remaining 173 could only be analysed on a damage basis. The high level of reconstruction allows the collision speeds to be calculated as well as ΔV, while the damage analysis only allows the calculation of ΔV. This technique was used to plot injury probability versus ΔV in side impacts, for the whole body or, for example, the chest, where struck vehicle ΔV might be thought to be a determinant of injury, as it influences occupant ΔV.

Such a tool is obviously of great interest to the accident investigator; however, CRASH users should be aware of the drawbacks in using the program which are inherent because of the assumptions that are made in the formulation of the mathematical model. It is not the intention of this section of the paper to criticise either the CRASH program or its use, but to emphasise the fact that not only must the data input be accurate, but also that only those collisions be reproduced which do not violate the assumptions on which CRASH is based. For example, a sideswipe type accident should not be simulated.

The third of the tests discussed above was reproduced using the CRASH 2 program, using the scene and vehicle damage data. Since the input data for the program was fully known, the vehicles' initial speeds and ΔVs as predicted by the model are thought to be as accurate as any that might be found from the reconstruction of an actual accident. Table 3 compares the results of the CRASH reconstruction with the data from the vehicle's on-board instrumentation.

The table illustrates two immediate points. Firstly, CRASH predicts that the target Mini was travelling backwards at 12 kph when hit by the bullet. This results from the final positions of the vehicles (see figure 2) being misaligned from the bullet's direction of travel. The program, therefore, assumes that the resultant velocity vector of the vehicles was the sum of the two velocity vectors at impact. In fact the movement from the bullet's heading must have been due to a rotational effect promoted by the centres of gravity not being aligned parallel to the bullet's line of travel, or to a 'steering' of the vehicles caused by non-symmetrical retarding forces, or angled, rolling tyres of the Marina.

Secondly, both vehicles' velocity changes and the bullet's initial velocity calculated by CRASH are about 30% higher than the instruments recorded. There are several factors in the program which contribute towards this difference. Firstly, the program at its present stage of development does not cope well with vehicles which stay together after a side impact so that the bullet and target are effectively retarded by the sideways scuffing of the target vehicle only. Secondly, large discrepancies can arise if the sideways translation changes to rolling movement with the vehicles turning from their path. In the absence of skid marks this would not be known in the field. Users should also consider the appropriateness of the crush characteristics used in the simulation to the actual car in question. In particular, the crash data used for side impacts for the 'minicar' category are based on a single, probably unrepresentative, side collision (14). It is a combination of these, and perhaps other factors, which have presumably contributed to the speed overestimates.

The simulation of this crash test has served to show some of the problems in the use of CRASH. It is believed that the impact data was better than or certainly as good as that which might be found from a real world accident, and care was taken to ensure that the program instructions were correctly followed. While CRASH may be a useful tool for the accident investigator, great care must be taken in the selection of cases which are simulated or the results may be misleading. A new version of the program, CRASH 3, is presently under development, and this may go some way towards solving some of the problems mentioned above.

Table 3 Comparison of CRASH 2 Results and Instrumentation Values from Test 3

Collision Variable (kph)	CRASH 2 Simulation*	Instrumentation Output+
Target Initial Speed	-12.1	0.0
Target ΔV	38.3	28.4
Bullet Initial Speed	62.4	45.5
Bullet ΔV	24.3	18.4

6 - CONCLUSIONS

The three reproductions of a real world accident discussed above have served to show that care must be taken in several areas to ensure that the results are reliable. Potentially, accident reproduction is a useful technique for the determination of injury tolerance, as long as its limitations are known and understood.

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* The program was run using the crash characteristics for a 'Minicar' for the target and 'Subcompact' for the bullet vehicles.

+ ΔV was calculated as the difference between the vehicles' initial speeds and their speeds at 120 ms when the instrumentation traces had stabilised, and were measured at the base of the B pillar. The target maximum speed was 29.7 kph.

In particular, the following problems were encountered in the programme:

a) the need for accurate and consistent vehicle alignment to ensure that the dummies are subjected to the same forces and accelerations as the occupants of the real accident,

b) the lack of knowledge on how well current dummies reproduce the movements of humans in accidents, especially in side impacts. This particularly refers to head/neck/shoulder design,

c) the need for a method of accurately assessing the parameters of the actual collision. CRASH is an attempt to provide such a tool, but its use is not straightforward at its present stage of development.

ACKNOWLEDGEMENTS

The authors would like to thank Mr P Jennings of TRRL for his considerable help in running the CRASH program, and also Leyland Cars for sponsoring the research project.

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