FRONTAL IMPACTS WITH SMALL PARTIAL OVERLAP: REAL LIFE DATA FROM CRASH RECORDERS

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ABSTRACT

Impacts with small overlap, or narrow offset impacts, are here defined as impacts with an overlap of less than 30%, often resulting in glance-off. Severe narrow offset collisions are characterised by high closing velocity, fairly low change of velocity, but major intrusion and high intrusion velocity, often resulting in severe injuries. For most car models the main part of the energy absorbing frontal structure is not engaged in this type of impact. Crash tests do not address the performance of the vehicle construction in this type of impact.

This paper presents results from real life collisions, collected in a unique data collection system, where the crash pulse has been recorded in the impact phase. Since 1992, approximately 100,000 crash recorders have been installed, and about 300 crash pulses have been recorded. A crash test with two vehicles of different design regarding the performance in narrow offset impacts is also presented. The study shows that the percentage of moderately and severely injured drivers was higher in impacts with an overlap below 30% than in impacts with an overlap more than 30%. It is also shown that the frontal structure is important for the performance in narrow offset impacts. Reconstructions of these collisions are also disussed.

BACKGROUND

Real life data shows that approximately 60% of all impacts are frontal impacts (Otte, 1990; O'Neill et al., 1994). Twentyone per cent of all frontal collisions have an overlap below 33% according to O'Neill (1994).

During recent years an increasing attention has been paid on how vehicles perform in impacts with partial overlap. New test methods are developed to better simulate real life impacts with partial overlap, generally 40% or 50%. These crash tests do not, however, address impacts with an overlap below 30 %, in which the main energy absorbing structure of most car models is not engaged. This type of impact, if severe, is characterised by a high closing velocity but with a relatively low change of velocity and high intrusion velocity. Most often this impact mode results in glance-off.

Narrow offset collisions usually generates a high risk of lower limb injuries, and the risk increases with increased intrusion (Thomas P, 1995). There is also a significant risk for severe skull/brain injuries (Thomas, 1994). The intrusion may be significant not only in the footwell area, but also for the instrument panel. Thomas (1994) shows that 38% of the severe injuries, MAIS 3+, are skull/brain and facial injuries in impacts with an overlap less than 30% and with a ΔV exceeding 60 km/h. Thomas (1994) also shows that in high speed impacts, ΔV over 60 km/h, with low overlap, the number of severely injured are higher compared to impacts with high overlap and with the same change of velocity. The change of velocity were in that study calculated on the basis of the crush energy.

A study by O'Neill (1994) showed that 12% of all frontal impacts with moderate or severe injuries were impacts with an overlap less than 33%. The study also showed that frontal collisions with an overlap less than 33%, produce moderate or severe injuries in 60 % and fatalities in 10% of those impacts. It is also shown that 14% of all fatal frontal two-car collisions had an overlap below 33% (O'Neill, 1994).

Change of velocity, ΔV, or Energy Equivalent Speed, EES (Zeidler et al. 1985), is often used to describe impact severity. In frontal impacts without significant intrusion, change of velocity, mean and peak acceleration has a correlation to injury risk (Kullgren, 1996; Kullgren, 1998). In frontal impacts with an overlap below 30%, and where the intrusions often are significant, intrusion velocity or closing velocity will probably be better correlated to injury risk.

Reconstructions of these impacts with computer simulations, like CRASH3 ("CRASH3 Technical Manual", NHTSA, 1986), are often difficult to assess since the algorithms only work properly when the vehicles in two-car collisions have a common velocity after the impact. In single accidents it is problematic if the vehicle not is hitting a fix object and if it has a remaining velocity. These types of impacts are not applicable for this type of reconstruction. It is also often difficult to estimate the collision impact site and the collision sequence, since there often is a glance-off after the impact phase, where the vehicles may be far away from each other after the impact. Estimations of closing velocities, or intrusion velocities if possible, are important for better reconstructions of these impacts and to better correlate impact severity to injury risk.

The aim of this study were to present the distribution of accidents and injured in narrow offset impacts and to analyse injury risk based on results from real life impacts, where the crash pulse has been recorded in the impact phase. The aim was also to analyse the performance of different vehicle constructions in narrow offset impacts, based on real life impacts and a crash test. Another aim was to discuss reconstructions of narrow offset impacts and to propose a new reconstruction method for this type of impact.

MATERIAL/METHODS

The impact severity was measured with a crash recorder. The crash recorder, called Crash Pulse Recorder (CPR), measures the acceleration time history in one direction. The crash pulses have been filtered with approximately 100 Hz. Change of velocity and mean and peak accelerations have been calculated from the crash pulses. The CPR and the analysis of the recordings from the CPR are further described by Aldman et al (1991) and Kullgren et al. (1995).

Since 1992, the CPR have been installed in approximately 100,000, comprising 4 different car makes and 15 models. The car fleet has been monitored for 5 years and every accident with a repair cost exceeding 7000 USD has been reported via a damage warranty insurance. The accident data collection system has been described by Kamrén et al., (1991). At the time this paper was written, approximately 400 accidents have been reported. Included in this study were injury data from 245 frontal collisions and crash recorder information from 177 frontal impacts, of which 23 with an overlap less than 30%.

Apart from the crash recorder information, injury data were collected and coded according to the Abbreviated Injury Scale (Association for the Advancement of Automotive Medicine, 1985), AIS85, with body localisation and injury type added. Belt use has been verified from interior inspections, and collisions involving unrestrained drivers, in total around 5%, were excluded from the study.

The impact severity parameters used in this study were change of velocity, mean and peak accelerations. In the distributions of accidents, the data were split in intervals for the included impact severity parameters. The injury risks were calculated for each interval, and smooth curve fits were used.

The crash test performed in this study was a two-car straight frontal collision with 28% overlap. The test speed was 58 km/h for each vehicle. The tested vehicles were a Saab 9000, 88 year model, and a Ford Scorpio, 87 year model. The test masses of the vehicles were 1420 kg for the Saab and 1370 kg for the Ford. Acceleration time history were measured at the sill below the left and right B-pillar. An HIII, 50 percentile dummy was used in the test, where head and chest accelerations and femur forces were measured.

RESULTS

Real life data

Fig 1 shows the distribution of frontal impacts with an overlap more than 30% and less than 30% at different change of velocities based on results from crash pulse recorders. The average ΔV for the frontal impacts with high overlap was 22.4 km/h, while it was 19.4 km/h for the impacts with low overlap. The average mean acceleration was 6.0 g for the high overlap impacts and 5.5 g for the low overlap impacts, and the average peak acceleration was 15.7 g for the high overlap impacts and 20.0 g for the low overlap impacts.

Twentytwo per cent of all frontal impacts included in the accident data in this study had an overlap below 30%. Sixteen per cent of the injured drivers in frontal impacts, had injuries more severe than MAIS 2 and 5% more severe than MAIS 3. Table 1 shows that there were 24% MAIS2+ injuries with an overlap below 30%, while there were 14% in impacts with an overlap exceeding 30%. The corresponding numbers for MAIS3+ injuries were 9% and 4%.

Thirtythree per cent of all moderately or severely injured drivers and 42% of the severely injured drivers were injured in impacts with an overlap below 30%. Table 2 shows the correlation between MAIS and ΔV in impacts with an overlap below 30%, where ΔV was measured with a crash pulse recorder. The MAIS2 injury at lowest ΔV occured at a ΔV of 14 km/h and the MAIS3 injury at lowest ΔV occured at a ΔV of 27 km/h.

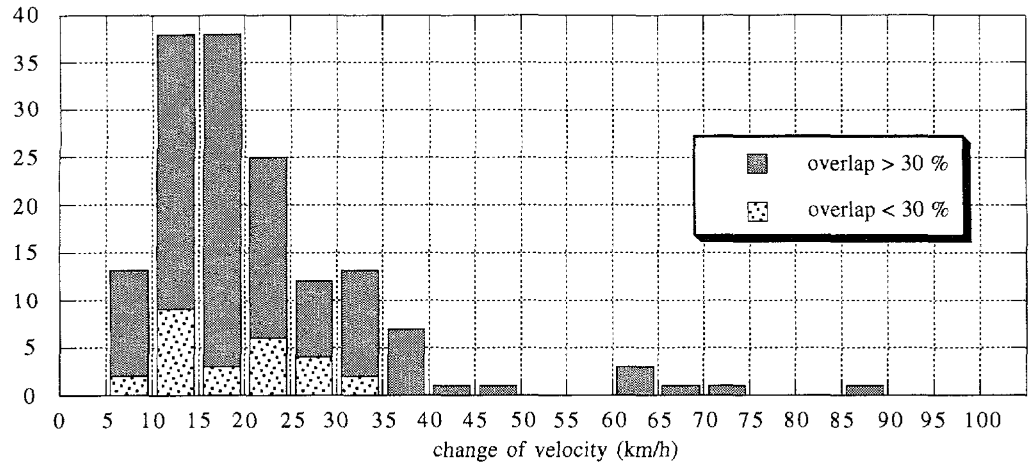

Figure 1. Number of impacts with an overlap more and less than 30% at different ΔV's.

Table 1.
Number of drivers with MAIS 2+ and MAIS 3+ injuries, versus overlap

Overlap classification	Restrained drivers number (%)	MAIS 2+ number (%)	MAIS 3+ number
<30%	55 (22)	13 (33)	5
≥30%	190 (78)	26 (67)	7
Total:	245 (100)	39 (100)	12

Table 2.
Number of driver injuries at different MAIS levels and measured ΔV in impacts with an overlap below 30%, n=23

	ΔV (km/h)							
MAIS for each body region	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
MAIS 0	-	-	4	1	4	1	-	-
MAIS 1	-	-	3	4	7	7	5	-
MAIS 2	-	-	2	1	1	3	-	1
MAIS 3	-	-	-	-	-	2	-	1
MAIS 4	-	-	-	-	-	-	-	1
MAIS 5	-	-	-	-	-	-	-	1

Table 3.
Number of head and leg injuries, MAIS 2+ and MAIS 3+, for driver and front seat passenger, in frontal collisions with an overlap less than 30%

		Head		Leg	
	Occupants	MAIS 2+	MAIS 3+	MAIS 2+	MAIS 3+
Driver, near side	13	4	2	7	2
Front seat passenger, far side	9	1	0	2	0

Table 4.
Number of injuries to drivers (near side) at different AIS levels to different body regions in frontal collisions, overlap less than 30%

Body region (driver)	AIS1	AIS2	AIS3	AIS4	AIS5
Head	10	3	1	1	1
Neck	18	-	-	-	-
Arm	10	5	1	-	-
Leg	10	6	2	-	-
Back	10	-	-	-	-
Chest	7	4	1	1	-

Table 3 shows that there were lower numbers of moderate and severe injuries for the front seat passenger at far side, than for the driver at near side in impacts with an overlap below 30%. Table 4 shows that the dominating injuries in these impacts were head, leg and chest injuries.

Fig 2 shows that the injury risk for impacts with low overlap is significantly higher than for impacts with high overlap. At a peak acceleration of 30 g there is 50% risk of a severe injury in high overlap impacts while it is approximately 100% in impacts with low overlap.

Table 5 shows specific accidents presented in depth. The included accidents are frontal two-car impacts with an overlap of between 25% and 30%. The change of velocity of the studied impacts varied between 27 km/h and 39 km/h. The injuries varied from MAIS1 to MAIS5. The performance of the included vehicles differed a lot, especially considering the amount of intrusion. In some cases there were significant intrusion in one of the two vehicles and low in the other. The accidents are presented in the appendix.

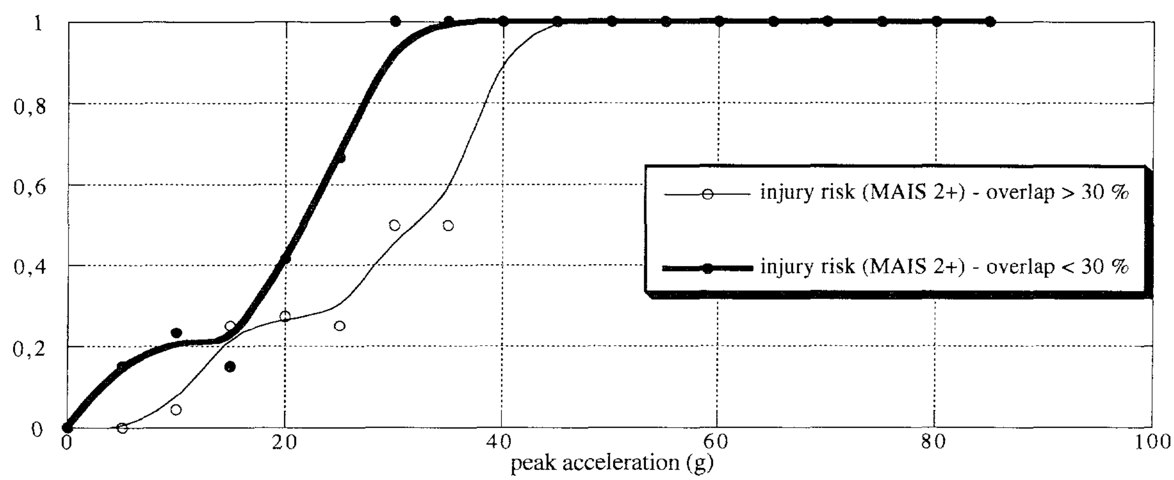

Figure 2. Injury risk (MAIS 2+) versus peak acceleration for impacts with an overlap more and less than 30%.

Table 5.
Accident cases with an overlap of approximately 30 %

	Case vehicle				Collision partner		
accident	Make and model	overlap (%)	ΔV (km/h) measured	MAIS driver	Make and model	ΔV (km/h) estimated	MAIS driver
1	Toyota Carina E -92	30	39.1	5	Volvo 244 -82	40	5
2	Toyota Camry -98	25	34.9	1	Saab 99 -82	45	5
3	Toyota Corolla -92	25	27.2	3	Opel Kadett -83	30	5

Crash test results

Fig. 7 and 8 shows crash pulses for the two vehicles in the frontal crash test with 28 % overlap. The test speed was 58 km/h for each vehicle, while the change of velocity was 22 km/h for the Saab and 24 km/h for the Ford. There was a significant difference in both exterior and interior deformation. The Saab 9000 had no intrusion in the footwell area while the Ford Scorpio had significant intrusion. Table 10 shows that the dummy measurements were low for both vehicles. The severity of the crash test was thus in the lower spectrum of the impact severity compared to the presented real life cases.

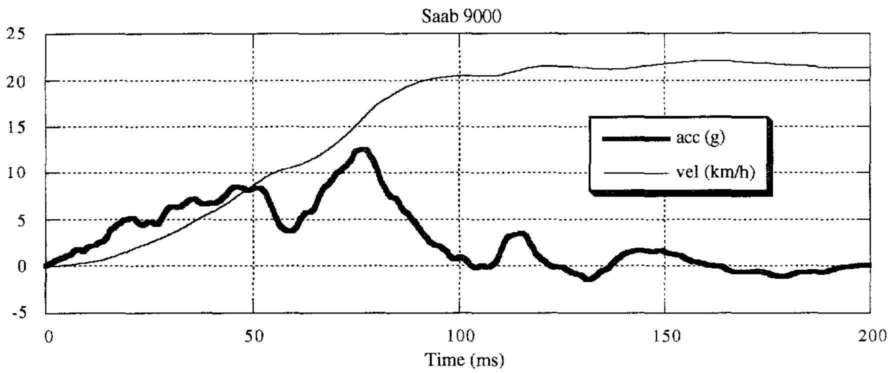

Figure 7. Crash pulse and change of velocity for the Saab 9000.

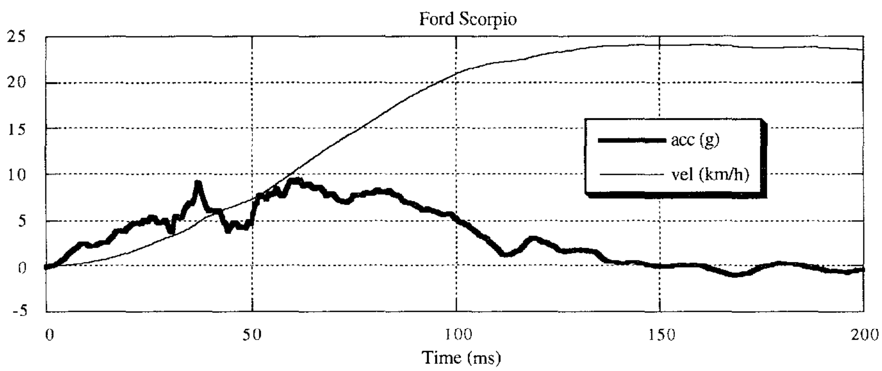

Figure 8. Crash pulse and change of velocity for the Ford Scorpio.

Table 10.
Measurements from the crash test in 58 km/h, 28% overlap

Test vehicle	Car body			HIII driver			
	ΔV (km/h)	mean acc (g)	peak acc (g)	Head res (g)	Chest res (g)	Femur L (kN)	Femur R (kN)
Saab 9000 -88	22	3.5	12.6	19	27	0.8	-
Ford Scorpio -87	24	3.8	9.4	48	24	2.4	1.6

Fig. 9. The Saab 9000 and the Ford Scorpio in the crash test.

DISCUSSION

Impacts with an overlap less than 30% produce a lot of severe injuries according to several studies (O'Neill, 1994; Thomas, 1994; Thomas, 1995). In this study 22% of all frontal impacts had an overlap below 30%. A study by O'Neill (1995) shows a corresponding number of 21%. There are, however, significant higher numbers of severely injured occupants in impacts with low overlap compared to impacts with high. As shown in Table 1, the proportion of moderate or severe injuries are higher in impacts with an overlap below 30%.

Severe narrow offset impacts are characterised by a high closing velocity, while the change of velocity could be relatively low. They are often connected with large intrusion and high intrusion velocity. Closing velocity is one impact severity parameter probably better correlated to injury risk than for example change of velocity. Intrusion velocity would probably be the parameter best correlated to injury risk if possible to measure or estimate. From Fig. 2 it is shown that other impact severity parameters than peak acceleration influence the injury risk for the driver at intrusion position. When plotting mean acceleration and ΔV versus injury risk, a similar difference between low and high overlaps can be seen. This also results in that the outcome for a driver, near side, and a front seat passenger, far side, is very different.

In reconstructions of collisions are often ΔV or EES used as impact severity parameters. Most reconstruction methods will give large errors in ΔV calculations in impacts with glance-off, mainly because the impact type is not applicable for most reconstruction programs, but also because ΔV sometimes is used synonymously with EES (Zeidler et al., 1997). Change of velocity calculated from the EES of the involved vehicle or vehicles will be too high since the energy needed to obtain a certain ΔV in an impact with glance-off is higher than if the vehicle would stop to 0 km/h with the same ΔV. If only one vehicle is available after an accident with two vehicles involved, a relevant reconstruction will be impossible to obtain. To be able to get a reliable change of velocity in an impact with glance-off, on board measurement technique is necessary. To be able to have relevant impact severity measurements in these impacts it is important to estimate the closing velocity, or if possible intrusion velocity.

The closing velocity in the presented real life accidents were significantly higher than in the performed crash test. An increased closing velocity will increase the deformation, although the change of velocity could be the same. The severity of the crash test were in the lower spectrum compared to the severity of the real life impacts causing moderate or severe injuries. This is also obvious when studying the dummy measurements compared to the injuries in the real life impacts.

In a two-car collision with glance-off, the two vehicles are in contact for a certain time period. During that time period the vehicles are decellerating to a certain final change of velocity. The time duration of the pulse can be obtained from the recordings from the crash pulse recorder. This means that the time while the two vehicles have been in contact is measured. If the length of the contact area of the involved vehicles is measured, it can be related to the time duration of the crash pulse. This gives the average relative velocity between the two vehicles during the impact phase, which together with the measured ΔV provides a possibility to calculate the closing velocity. The closing velocity is probably the best parameter, possible to measure, for this impact type. The average closing velocity during the impact phase will in turn give a possibility of estimating the intrusion velocity. This must be further evaluated for the accident sample as well as in crash tests.

The performance in collisions with low overlap might vary between different vehicles. As shown in this study the difference can be substantial. The architecture of the frontal structure seems important for the performance in this type of impacts. The tested Saab 9000 has a large distance between the side members, while the Ford Scorpio has a more traditional structure with closer distance between the side members and a longitudinal mounted engine. It seems beneficial to have a widely distributed energy absorbing area in the front. This is also shown in the real life accident no.2, see appendix. Stiffer structure is also a fact to take into account considering the outcome in that accident.

The risk of intrusion in impacts with small overlap should also be considered for impacts with guard-rails and other road side objects.

CONCLUSIONS

- Impacts with an overlap below 30 % produce a lot of severe injuries.
- The frontal structure of vehicles is important for the performance in narrow offset impacts.
- Reconstructions of this type of impacts requires on board measurement technique.
- It is possible to estimate closing velocity in glance-off impacts from the recorded crash pulse and the length of the contact area.

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APPENDIX

Accident 1

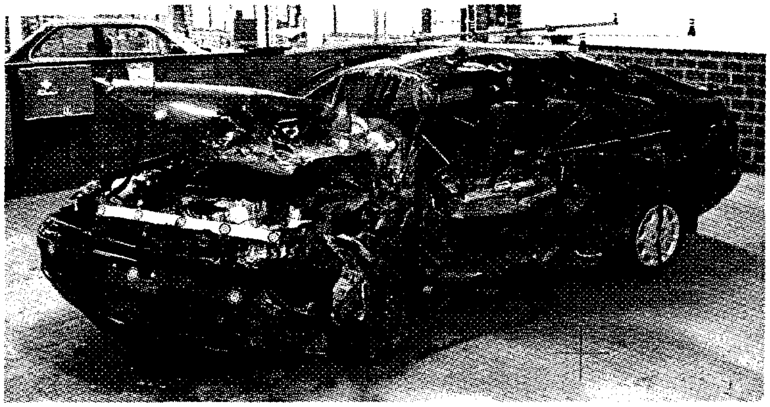

Figure 1. Case vehicle, Toyota Carina E, 1992.

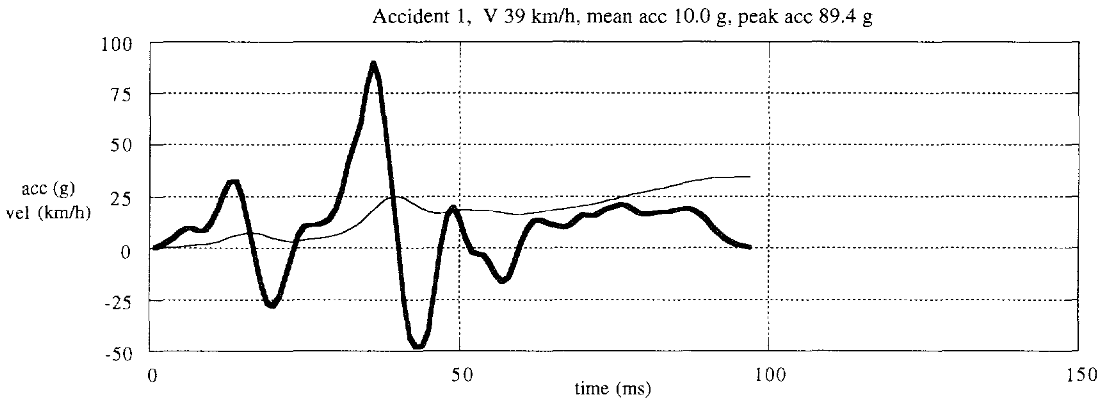

Figure 2. Crash pulse and change of velocity for the Toyota Carina E in accident 1.

Table 1.
Occupant injuries, MAIS, in accident 1

Body region	Case vehicle Pos 1 belted	Case vehicle Pos 2 belted	Case vehicle Pos 5 unbelted	Partner Pos 1 unbelted
Face / head	5	-	1	5(dead)
Neck	-	-	-	-
Arm	3	1	-	1
Leg	2	-	1	2
Pelvis	-	-	-	-
Back	-	-	-	-
Chest	4	1	-	3
Abdomen	-	-	-	-

Accident 2

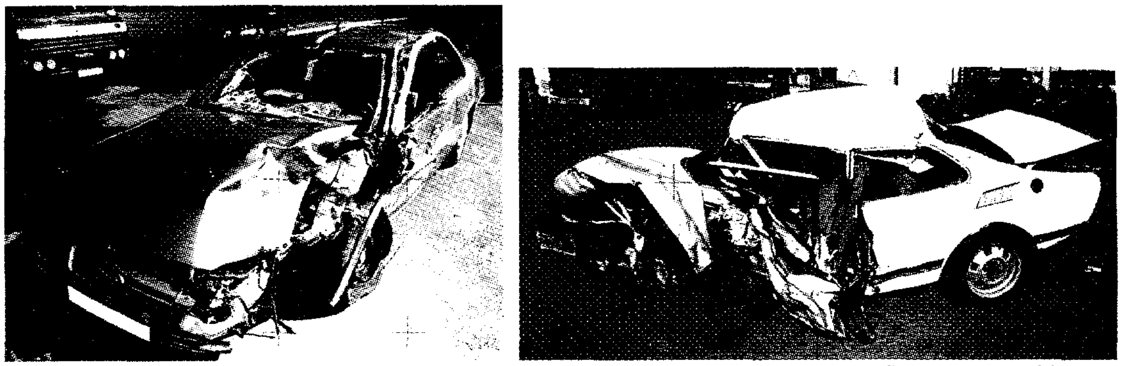

Figure 3. Case vehicle, Toyota Camry, 1997 and collision partner, Saab 99, 1982.

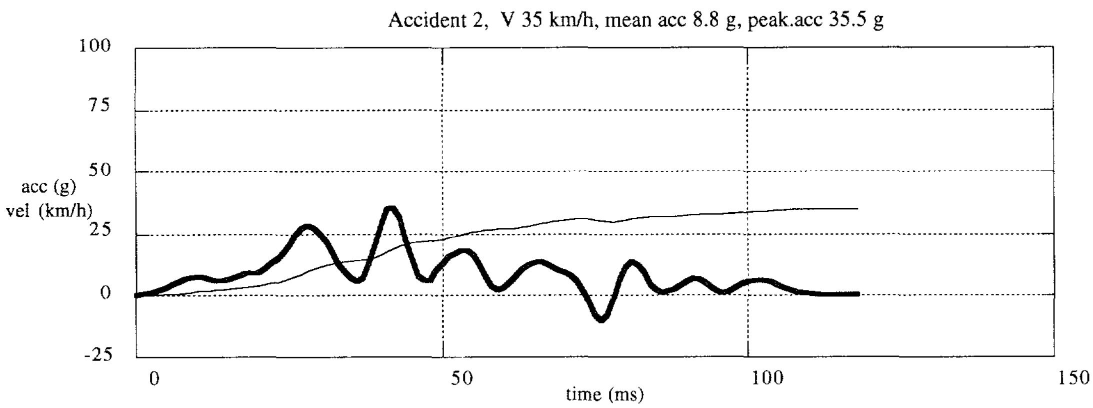

Figure 4. Crash pulse and change of velocity for the Toyota Camry accident 2.

Table 2.
Occupant injuries, MAIS, in accident 2

	Case vehicle	Collision partner	
Body region	Pos1 belted	Pos 1 belted	Pos 2 belted
Face / head	1	4	3
Neck	1	-	-
Arm	1	3	2
Leg	-	3	2
Pelvis	1	3	-
Back	1	5	-
Chest	-	6 (dead)	5 (dead)
Abdomen	-	4	4

Accident 3

Figure 5. Case vehicle, Toyota Corolla, 1992.

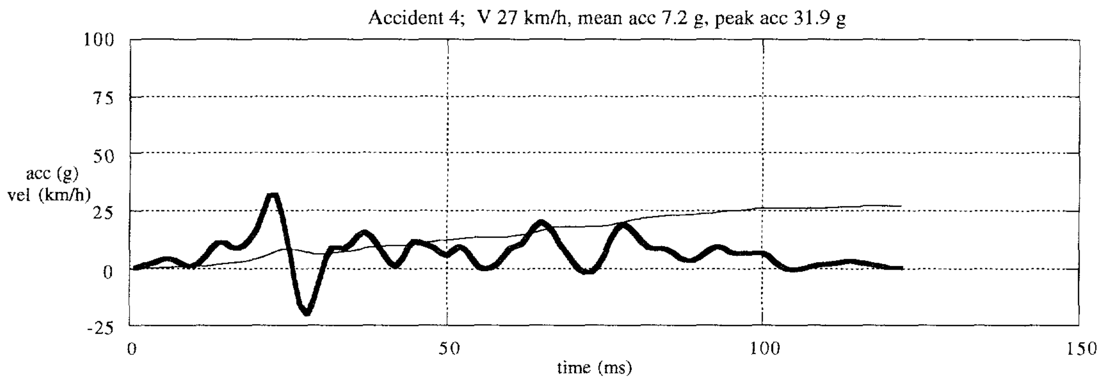

Figure 6. Crash pulse and change of velocity for the Toyota Corolla in accident 3.

Table 3.
Occupant injuries, MAIS, in accident 3

	Case vehicle			Partner	
Body region	Pos 1 belted	Pos 2 belted	Pos 5 belted	Pos 1 belted	Pos 2 belted
Face / head	-	-	-	?	2
Neck	1	-	-	?	-
Arm	-	2	1	?	1
Leg	3	2	1	?	-
Pelvis	-	-	-	?	-
Back	1	-	1	?	-
Chest	2	2	1	5(dead)	-
Abdomen	-	-	-	?	-