AN ANALYSIS OF THE FIELD PERFORMANCE OF SOME STEERING SYSTEMS COMPLYING WITH CURRENT SAFETY LEGISLATION

by

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Introduction

In 1974 the Accident Research Unit published the results of a three year field and laboratory study designed to investigate the performance of steering systems specifically evolved to comply with FMVSS 203 and 204 and their European equivalents (1 - 3)*. These standards aim to control the horizontal intrusion of the steering wheel into the passenger compartment in a frontal impact and also limit the peak loads applied to the unrestrained driver's chest. Since 1974 a further 121 accidents involving unrestrained drivers striking the systems of interest have been studied. The purpose of this paper is to describe what has been observed in that period and to analyse the serious and fatal injury cases which form a subset of the 1974 data in combination with the serious and fatal injury cases that have been collected subsequently.

Cases were selected for inclusion in the analyses if an unrestrained driver dissipated all his torso energy in contact with one of the selected designs of steering system. This constraint was placed on the data to provide field evidence which closely related to the tests required by current steering system standards. The steering systems chosen for study were selected as they are believed to reflect two broad design concepts. Axial compression columns rely on some form of energy absorbing unit incorporated below the upper column mounting bracket to limit loads applied to the driver's chest. All such columns in the present study also carry out their anti-intrusion function by a telescoping action in the column itself. Such systems are indirectly encouraged by current legislation as there is an attraction for the vehicle manufacturer in fitting a steering system 'package' which will virtually ensure compliance of his vehicle with both steering system standards. The second group of systems selected were the 'self aligning' wheel designs in which a deformable can is placed directly behind the steering wheel and the driver's energy is absorbed

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* Numbers in parentheses refer to references at the end of the paper.

by deformation of both this unit and the conventional steering column and facia. Such designs rely on other features of the bodyshell design and layout for compliance with the anti-intrusion part of the standard and consequently may not be viewed so favourably by a manufacturer seeking standard's approval.

The 1974 study was based on accidents gathered by in-depth investigation and the sampling system was such that incidents involving either high energy or serious or fatal injury were followed up. After 1974 the sampling requirements were changed and the cases were drawn from those accidents in which at least one occupant of a car was seriously or fatally injured. Thus, after 1974 a driver suffering no or slight injury would only come into our sample if someone else in his vehicle received serious or fatal injury. This change in sampling criterion makes direct combination of the cases collected during the two periods invalid. However, for the duration of the whole study period accidents in which drivers have been seriously or fatally injured have been collected and the entire sample can be examined to describe injury patterns and safety system performance within this limitation. Consequently, in the current analysis all relevant additional cases collected since 1974 will be described first and then the serious and fatal incidents which form a subset of both this data and the cases collected prior to 1974 will be combined.

The official U.K. category of serious injury is the one referred to here and includes as a minimum requirement an overnight stay in hospital or the presence of a fracture. The fatal category, again as used by the police, includes anyone who dies within 30 days of the accident. In practice, this serious injury classification broadly coincides with injuries of AIS 2 and above (4).

Axial Compression Column Cases collected since 1974

The make and model break-down amongst the additional 96 cases is shown in Appendix 1. By first examining all cases irrespective of injury severity, it is possible to compare the column function for the low injury severity cases with that observed for the serious or fatal injury subset which will be described later. As has been explained above, the uninjured or slightly injured drivers will be under-represented in this data.

The models analysed contain a range of column designs as shown in table 1.

Table 1: Types of axial compression column designs.

Type of Column	Number
Telescoping steering shaft with 'mesh' energy absorbing jacket	25
Telescoping steering shaft with 'convoluted tube' energy absorbing jacket	52
Japanese variants on above	5
'Ball' columns	14

The AIS for each body area on every driver has been assessed and the highest AIS on each driver is shown below in table 2.

Table 2: Distribution of highest AIS for 96 unrestrained drivers impacting axial compression columns.

Highest AIS	Number
0	0
1	23
2	27
3	18
4	8
5	16
6	4

The inadequacy of shear capsule separation alone as a measure of driver ride-down has been discussed previously (3). Where no facia movement occurs, shear capsule separation provides a good indication of driver ride-down. However, when there is facia movement or mounting bracket rotation, such damage has to be taken into account to establish what proportion of the apparent shear capsule movement reflects driver ride-down. This ride-down is designed to be available in addition to that provided by wheel, facia and column bending. For this sample, the presence of ride-down is shown in table 3. It is of note

Table 3: Incidence of significant additional ride-down in axial compression columns

	Number
Significant additional ride-down provided by column compression	7
No significant additional ride-down provided by column compression	86
Not established	3

that only 8% of these columns provided any additional ride-down for the driver. The amount of column compression from the top amongst the 7 cases in which such movement occurred is shown in table 4, illustrating that in 71% of the ride-down cases less than 2.5 cm of movement was provided.

Table 4: Column compression due to driver loading.

Compression (cm)	Number
0 - 0.5	1
0.6 - 2.5	4
2.6 - 5.0	1
5.1 - 7.5	0
more than 7.6	1

The total column compression is shown in table 5. In the designs studied, this measurement reflects a combination of column movement produced by both intrusion and driver ride-down. The observed amounts of column compression are generally small and thus it can be concluded that columns are not bottoming out due to primary damage and thus being prevented from stroking from the top.

Table 5: Total column compression.

Compression (cm)	Number
0 - 5.0	71
5.1 - 10.0	10
10.1 - 15.0	2
Not known	13

Axial Compression Column Cases - The Serious and Fatal Injury Sub-Sample.

Having examined the column function in all cases collected since 1974, the subset of drivers sustaining AIS 2 or above in any body area has been selected. As explained previously, this group approximates to the seriously and fatally injured drivers and patterns of injury and column function can be meaningfully described for this group. The 73 drivers so selected from the post-1974 study have been added to the 24 seriously or fatally injured drivers from the 1974 analysis who struck axial compression columns. The patterns of injury for these drivers is shown in table 6, and the multiplicity

Table 6: Injury patterns for drivers with highest AIS ⩾2. Axial compression columns.

AIS	Head and Neck	Chest	Abdomen	Higher of Chest or Abdominal AIS	Legs
0	5	31	74	28	18
1	24	16	4	17	28
2	43	3	2	4	22
3	5	19	2	17	28
4	1	11	7	11	1
5	15	16	8	19	0
6	4	1	0	1	0
Total	97	97	97	97	97

of injury is apparent together with the considerable importance of the steering system as an injury source in this sample. It should be remembered that due to the selection of cases for this analysis, all these people dissipated their torso energy solely on the steering system, and all the chest and abdominal injuries above can thus be attributed to this source. For these 97 occupants whose highest AIS in any body area was ⩾2, some 44% received their most severe or equal most severe AIS from the steering system. No significant additional ride-down by axial compression of the column was provided for 88% of those classified as seriously or fatally injured. Some ride-down was available for 7% of this group and in five cases the column performance was not fully established.

The Equivalent Test Speed (E.T.S.) distribution for all 97 cases is shown in table 7. In addition, this table illustrates the E.T.S. distribution for those cases where the chest or abdominal injury was AIS 2 or above. As would be expected, there is a strong statistically significant relationship between the frequency of serious chest and abdominal injury and E.T.S.

Table 7: E.T.S. distribution for 97 drivers with highest AIS ≥ 2. Axial compression columns.

E.T.S. (mph)	Highest AIS ≥ 2	Chest or Abdominal AIS ≥ 2
5 - 10	1	0
10 - 15	6	1
15 - 20	10	4
20 - 25	22	8
25 - 30	19	8
30 - 35	15	12
35 - 40	4	4
40 +	5	5
Not known	15	10
	97	97

It can be seen that, in general, serious wheel induced chest or abdominal injury only appears to occur above an E.T.S. of 15 mph. As it is believed that an unrestrained dummy contacts the steering system in a barrier test at a velocity close to the vehicle's speed of impact, this data perhaps suggests that a torso velocity of 15 mph, as specified in current standards, may be examining what would be a largely non-injury chest and abdominal impact for most drivers.

The column designs involved in these 97 cases are shown in table 8, illustrating that a variety of designs are covered by this analysis. Of these 97 columns 48% had significant static bends below the upper mounting bracket and it seems probable that dynamically an even higher proportion of columns had a bend in the region of the telescoping section. Such bends, which can be initiated by vehicle crush, are capable of inhibiting column compression due to torso impact (2, 3) and this is the likely explanation for some of the performance seen in the field. In addition, high torsional loads can be developed in the telescoping steering shafts due to rapid redirection of road wheels and steering gear by both the front end crush of the vehicle and direct interaction with the impacted object. Such torsional loads are believed to increase greatly the loads required for shaft compression and could be the explanation for the failure of some apparently straight columns to collapse at loads which cause major injury to the driver.

Table 8: Types of axial compression columns struck by drivers with highest AIS ≥ 2.

Type of column	Number
Telescoping steering shaft with 'mesh' energy absorbing jacket	30
Telescoping steering shaft with 'convoluted' energy absorbing jacket	52
Japanese variants on above	3
Ball column	12
Total	97

The limited stroking of these columns is shown by the generally small amounts of total column compression seen in real accidents (table 9).

Table 9: Total column compression

Compression (cm)	Number
0 - 5 cm	65
5.1 - 10 cm	14
10.1 - 15 cm	3
Not known	15

It was believed that the concentration of load on the driver's chest due to wheel deformation might be an influencing factor on chest and abdominal injury and thus the presence of such an occurrence was examined in each case. In this context, load concentration was judged to have occurred if wheel distortion was such that the whole front face area of the spokes was not available for torso impact. In 62% of the cases the steering wheel deformed in such a way as to produce load concentration on the driver's chest or abdomen. If those 52 people who received an AIS of 2 or more in the chest or abdominal regions are considered as a group, some 85% of them experienced load concentration from the wheel.

As a final description of the drivers who sustained a highest AIS ≥2 in any body area, table 10 contains their sex and age distribution and the rear loading experience described with respect to the relative severity of steering wheel induced injury and the presence or absence of serious chest or abdominal injury.

Statistical testing of the data in table 10 showed that there were no significant differences at the 5% level of confidence in the relative severity of the wheel induced injury with respect to age, sex and rear loading or in the AIS score for the chest and abdominal injury with respect to the sex of the driver. There was a significant difference at the 10% level for chest and abdominal

Table 10: Sex, age and rear loading experience of drivers with highest AIS ⩾ 2. Axial compression columns.

	Wheel induced chest and abdominal injury		Chest or abdominal injury	
	most severe	not most severe	⩾ 2	< 2
Sex				
Male	39	45	45	39
Female	4	9	7	6
Age				
10 - 19	1	0	1	0
20 - 29	10	20	10	20
30 - 39	5	11	8	8
40 - 49	7	8	9	6
50 - 59	13	8	14	7
60 - 69	3	6	6	3
⩾70	0	1	0	1
not known	4	0	4	0
Rear loading				
None	24	39	29	34
From seat only	9	11	12	8
From seat and luggage	2	1	2	0
From seat and rear passenger	6	3	7	3
Not known	2	0	2	0

injury severity versus age with elderly drivers suffering more serious injury. Also, the incidence of major rear loading was significantly different when those who suffered serious chest and abdominal injury were compared with those who did not, but again only at the 10% level of confidence. It should be pointed out that no attempt was made to examine the E.T.S. distributions between sexes, age groups and types of rear loading since the numbers of cases were too small.

Axial Compression Column Cases - The Fatal Sub-Sample

Within this group of 97 cases there were 29 fatalities and the column performance and injury patterns for these people will be described briefly. In 72% of these cases the wheel induced injury was the most severe or equal to the most severe. For 86% of the drivers no additional ride-down was provided by axial compression of the column; only one column did provide any ride-down and in three cases insufficient information was available to make a decision.

Wheel distortion which resulted in load concentration occurred in 97% of the fatalities. Table 11 describes the rear loading experience and the sex and age distribution for this fatal sub-sample.

Table 11: Sex and Age distributions and rear loading experience for fatalities. Axial compression columns.

	All cases	Wheel induced injury most severe
Sex		
Male	25	19
Female	4	2
Age		
10 - 19	1	1
20 - 29	5	5
30 - 39	5	2
40 - 49	6	4
50 - 59	6	4
60 - 69	4	3
70 +	0	0
Not known	2	2
Rear loading		
None	16	12
Seat	7	4
Seat plus luggage	1	1
Seat plus passenger	4	3
Not known	1	1

The E.T.S. distribution for these cases is shown in table 12.

Table 12: E.T.S. distribution for the fatalities.

E.T.S. (mph)	Number
15 - 20	1
20 - 25	3
25 - 30	1
30 - 35	9
35 - 40	3
40 +	5
Not known	7

The fatalities were not associated with any particular design of steering column as shown in table 13.

Table 13: Types of columns struck by fatalities.

Type of column	Number
Telescoping steering shaft with 'mesh' energy absorbing jacket	11
Telescoping steering shaft with 'convoluted tube' energy absorbing jacket	13
Ball column	5

As a final description of the fatal sub-sample, the pattern of injury is illustrated in table 14.

Table 14: Patterns of injury amongst the fatalities.

	Highest AIS	Head and Neck	Chest	Abdomen	Higher of Chest and Abdominal AIS	Legs
AIS 0	0	0	0	13	0	6
1	0	6	0	0	0	5
2	0	4	0	0	0	8
3	1	1	7	2	5	9
4	1	0	5	6	4	1
5	22	14	16	8	19	0
6	5	4	1	0	1	0

Again it should be remembered that the chest and abdominal injuries in this sample are all due to steering system contact.

Summary of Results for Axial Compression Columns

The results obtained by analysis of these 120 cases of unrestrained driver impacts with axial compression columns are:

1. No such column has been seen to use up all its available telescoping potential in any case in this sample.

2. The great majority of the columns in this sample failed to provide any additional ride-down for the drivers. Where ride-down did occur, it was generally small. This observation was found to be true at all driver injury severities.

3. The steering system was a major source of injury in this sample and its relative importance increased in the fatal accidents.

4. Residual bending of the telescoping sections of these columns was observed

frequently and it seems likely that dynamically such bending would be even more common. Previous work has shown that bending can inhibit column collapse. Dynamic torsional loads in the telescoping steering shafts could be an additional cause of column malfunction.

5. In all the fatal incidents, except one, major steering wheel distortion resulted in load concentration on the driver's chest and abdomen. Such load concentration occurred in 85% of the cases where injuries of AIS 2 or more were sustained in the chest or abdomen and 62% of the incidents where drivers suffered injuries of AIS 2 or more in any body area.

6. In accidents where the E.T.S. was estimated, only one injury to the chest or abdomen of AIS 2 or more occurred at a speed of 15 mph or less, the test speed specified in current standards.

Self Aligning Steering Wheel Cases collected since 1974

Since the 1974 analysis, 25 additional cases of unrestrained drivers dissipating all of their torso energy on self aligning wheels have been studied. The distribution of highest AIS in any body area for these drivers is shown in table 15. There were two fatalities in this sub-sample. Throughout the following tables the numbers relating to fatalities will be placed in brackets.

Table 15: Distribution of highest AIS for drivers striking self aligning systems.

AIS	Number
0	0
1	7
2	6
3	9
4	1
5	1 (1)
6	1 (1)
Total	25

Self Aligning Wheels - The Serious and Fatal Injury Sub-Sample

Once again the subset of 18 cases, from the additional data, in which the driver sustained an injury of AIS 2 or more in any body area has been combined with the similar subset of cases drawn from the 1974 analysis to give a total sample of 37 cases of seriously or fatally injured people. Again, all occupants were unrestrained and all the torso contacts were solely with the steering system.

The make and model break-down amongst these cases is shown in Appendix 1. Within these vehicles, 2 steering wheel designs have been used. Both involve a short convoluted can placed directly behind a wheel with broad sheet metal spokes. The orginal design used a three-spoke wheel and this was later changed to a two-spoke version. In both cases the wheel is placed on a conventional rigid steering column. The nature of the wheels in this sample is shown in table 16 but, as can be seen, the numbers of each design available are too small

Table 16: Self aligning wheel designs in serious and fatal sample.

Design	Number
Three-spoke wheel	26 (3)
Two-spoke wheel	11 (1)

to allow separate analysis. However, the indications from examination of the accidents are that both systems align better with the driver's chest when struck 'on spoke' than 'off spoke'. As the two-spoke version has a greater length of unsupported rim, the chances of it being struck in its least favourable orientation are higher and thus its overall field performance may be slightly inferior to that of the earlier design.

When mode of damage to the convoluted can behind the wheel was compared with that generated under standard 'Blak Tufy' tests, it was found that in only 26% of the 23 cases where full information was available, were the test and accident modes similar. Previous work has shown that accident-like modes can readily be generated under test by increasing the mounting angle of the steering system by as little as 10^0, simulating either dynamic column movement or a rising driver trajectory or a combination of both (3).

Load concentration was assessed using the same criterion as used for the axial compression column cases, and for the self aligning wheels 38% of the 37 cases sustained such damage. For those suffering a chest or abdominal injury of AIS 2 or more 45% experienced load concentration.

The patterns of injury for those with an AIS of 2 or above in any body area are shown in table 17.

Table 17: Pattern of injury for those with highest AIS ≥2. Self aligning wheels.

AIS	Head and Neck	Chest	Abdomen	Higher of Chest or Abdomen	Legs
0	3	13	31 (2)	12	4 (1)
1	15 (1)	13 (1)	4	14 (1)	9
2	12 (1)	4	0	4	15 (2)
3	3	5 (1)	0	5 (1)	8 (1)
4	2 (1)	1 (1)	1 (1)	0	1
5	1	1 (1)	1 (1)	2 (2)	0
6	1 (1)	0	0	0	0

In only 8 of these 37 cases did the wheel-induced chest or abdominal injury have the highest or highest-equal injury score; in 2 of the 4 fatals this was so.

The E.T.S. distribution for these cases is shown in table 18. The one case of AIS ≥2 chest injury at an E.T.S. of 10 - 15 mph was notable for the considerable additional loading coming from the load platform in a van.

Table 18: E.T.S. distribution. Self aligning wheels.

E.T.S. (mph)	Number in sample with highest AIS in any body area ≥2	Number in sample with chest and abdominal AIS ≥2
10 - 15	2	1
15 - 20	2	0
20 - 25	9	1
25 - 30	7	1
30 - 35	6 (2)	4 (1)
35 - 40	2 (1)	1
40 +	2 (1)	0
Not known	7	3

The sex and age distribution and the rear loading experience for these drivers is given in table 19. These distributions are not significantly different from

Table 19: Sex, age and rear loading. Self aligning wheels.

		Number
Sex	Male	34 (4)
	Female	3
Age	10 - 19	2
	20 - 29	10
	30 - 39	7 (1)
	40 - 49	8 (1)
	50 - 59	6 (2)
	60 - 69	3
	70	1
Rear loading	None	23 (1)
	Seat only	10 (2)
	Seat and luggage	1
	Seat and rear occupant	3 (1)

those for the axial compression column cases.

Summary of Results for Self Aligning Wheels

Analysis of these 37 unrestrained drivers who contacted self aligning steering wheels and received an injury in any body area with an AIS ≥ 2 has shown that:

1. The mode of damage of the convoluted can behind the wheel was similar to that produced under test in only 26% of the cases.

2. Load concentration due to distortion of the plane of the spokes was observed in 38% of the cases.

3. Wheel induced chest or abdominal injury was most severe or equal most severe in 22% of the cases.

4. Only one serious chest or abdominal wheel induced injury was observed below an E.T.S. of 20 mph.

Comparison of axial compression column and self aligning wheel cases

The comparative performance of the two types of steering systems in accidents producing serious or fatal driver injury can be examined. Statistical comparison of the E.T.S. distributions and the rear loading experience, age and sex distributions of the drivers striking the two systems revealed no significant differences. However, the drivers striking self aligning systems sustained their highest or highest equal AIS from the steering system in 22% of the cases whereas for those striking axial compression systems the equivalent figure was 44%. This difference is significant at the 2% level of confidence and indicates that, within this serious and fatal sample, axial compression columns are making a greater contribution to injury than self aligning wheel systems.

This trend could be explained by differences in other parts of the car. For instance, if the cars with self aligning wheels also contained knee and head impact areas that were markedly more agressive than those available in cars with axial compression columns, the same trend could emerge without its being a true reflection of a difference in steering system performance. In practice, the opposite appears to be true and the absence of the relatively stiff column support structures required for axial compression columns seems to leave the self aligning wheel vehicles in this study with less dangerous knee impact areas. The absence of an early high load knee contact also seems to give the driver a slightly lower trajectory than otherwise and this has benefits in keeping the driver's head below the windscreen header rail (2, 3). It is thus felt that the difference in the relative contribution of the two steering systems to serious and fatal injury does indeed reflect a real difference in their performances.

Further, the incidence of chest or abdominal injury of AIS 2 or above was found to be significantly different at the 2% level of confidence. In the axial compression cases, 54% of drivers sustained such injuries whereas in cars fitted with self aligning wheels 30% of drivers received injuries of this severity. If the occurrence of chest or abdominal injuries of AIS 3 or above for the two steering systems is examined statistically, there is found to be a significantly higher incidence, at the 1% level of confidence, of these injuries amongst drivers striking axial compression columns.

Implications for Safety Standards controlling Steering System Performance

Test work conducted on steering systems believed to be representative of the designs analysed in this paper has been reported in full in reference 2 and in summary form in reference 3. These results, together with this field analysis, allow the following suggestions to be made regarding improvements to the current standards.

Present tests do not reproduce the modes of wheel and column damage observed in the field. Axial compression columns provide additional ride-down under test but rarely do so under real accident loading. Steering wheel damage is relatively minor under test but frequently extensive in the field. This wheel damage results in load concentration on drivers' chests. The modes of damage of the convoluted cans of self aligning wheels in accidents tend to be different from those observed under test. These differences can all be overcome by mounting the steering system at approximately 15^0 above its normal mounting angle in the present test rig.

In the field, load concentration seems to be associated with severe chest and abdominal injury and, indeed, it would be most surprising if this were not so. The current peak load injury criterion takes no account of load distribution and until this is reflected in the injury criterion, it is unlikely, in our opinion, that great improvements will be made in the fidelity of the testing. Reliable dynamic measurement of load distribution is not easily achieved and it is suggested that a simpler approach might be useful. The two features which this work suggests are particularly beneficial are:

1. that a reasonable sized total area of loading is available for the chest impact and
2. that this area is aligned with the chest before loads become too high.

The simplest way of specifying such performance might be to require a certain minimum steering wheel spoke area, as defined before the test and bounded by a suitable number of event markers, to be in contact with the dummy's chest before the resultant load has reached a given limit. The values chosen for the loading area and the load by which alignment must have occurred could best be defined by a series of tests on a range of designs of steering systems with known field performance. In this way the modified procedures could be crudely calibrated from field evidence. By way of an example, the self aligning systems in our tests presented a spoke area in excess of 150 cm^2 before loads had exceeded 5 kN. These results were achieved even when the system was tested 15^0 above its normal mounting angle. In comparison the axial compression column when tested 15^0 above its normal mounting angle produced no ride-down, considerable wheel distortion and offered a spoke contact area of the order of 30 cm^2 at peak load. The values of peak load in the two systems tested in this way were in the range of 7 - 10 kN, all clear 'passes' as judged by the current criterion.

More work is required on a greater range of steering systems before definitive figures can be suggested for the appropriate column mounting angle to be tested and the area and alignment loads which should be required. It is hoped, however, that the above principle can be discussed and may possibly form a useful base for manufacturers' 'in-house' standards.

Conclusions and Observations

The analysis of these 164 cases has revealed the same trends as were apparent in the initial analysis published in 1974 (2, 3). The larger numbers in the present analysis allow greater confidence to be placed on the conclusions and illustrate that the shortcomings evident in 1974 in the steering column standards are still with us. The main points to emerge are:

1. With very few exceptions, axial compression steering systems in the models of cars in this sample, designed to comply with current Federal and European Safety Standards, are failing to operate in their designed mode in serious and fatal injury accidents. This malfunction seems to be brought about by drivers striking systems that have sustained damage due to primary crush at trajectories that are not tested by current legislation.

2. The consequences of the column malfunction are that major steering wheel deformations are occurring which result in load concentrations on the drivers' chests. It seems highly likely that such load concentration must lower the loads that can be tolerated without injury. The amount of wheel damage seen in cases where serious chest injury has resulted is quite different from that produced under standard testing conditions.

3. The self aligning steering systems are generally presenting larger areas for drivers' torso impacts in accidents. Mechanically they seem to tolerate disruption due to primary damage much more satisfactorily than axial compression systems and are capable of offering protection in a far greater variety of crash conditions.

4. For drivers suffering serious or fatal injury, those striking axial compression columns were more likely to receive their most severe injury from the steering system than those who struck self aligning wheels. Also, drivers striking axial compression columns received chest or abdominal injuries of AIS 2 or above and AIS 3 and above more frequently than drivers contacting self aligning wheels. All these differences were statistically significant at at least the 2% level of confidence. It was demonstrated that no significant difference existed between the E.T.S. distributions, rear loading experience and sex and age distributions for the two groups of drivers.

5. In the great majority of field cases the modes of damage to the steering systems were unlike those produced by tests required by current standards.

6. Torso impact velocity of 15 mph appears to be low when compared with the severity of accidents causing serious wheel induced chest and abdominal injury in the field.

7. Simple modifications to the current dummy torso tests have been suggested which allow a) field accident damage to be more accurately reproduced and b) the injury criterion to be modified in such a way as to encourage systems with good load spreading properties.

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APPENDIX 1

DISTRIBUTION OF CAR MAKES AND MODELS

	ALL INJURY SEVERITIES COLLECTED AFTER 1974	SERIOUS AND FATAL CASES			ALL FATAL CASES
		COLLECTED BEFORE 1974	COLLECTED AFTER 1974	TOTAL	
SELF ALIGNING WHEEL CASES					
Ford Escort I	10	4	7	11	1
Ford Escort II	9	-	6	6	1
Ford Capri I	3	14	2	16	2
Ford Capri II	3	-	3	3	-
Ford Zephyr	-	1	-	1	-
TOTAL	25	19	18	37	4
AXIAL COMPRESSION COLUMN CASES					
Ford Cortina III (pre.E.Facia)	22	11	17	28	6
Ford Cortina III (E.Facia)	21	-	17	17	7
Ford Cortina IV	2	-	1	1	-
Ford Granada	7	-	6	6	-
Vauxhall H.A. Van	1	-	-	-	-
Vauxhall H.B. Viva	-	4	-	4	1
Vauxhall H.C. Viva	5	2	3	5	-
Vauxhall Firenza	2	1	1	2	1
Vauxhall FD Victor	1	6	1	7	4
Vauxhall FE Victor	5	-	3	3	2
Vauxhall Chevette	3	-	2	2	-
Opel Record	1	-	1	1	-
Opel Manta	2	-	2	2	1
Opel Kadett	2	-	2	2	1
Datsun 100A	3	-	1	1	-
Datsun 120	4	-	4	4	1
Datsun 160B	1	-	1	1	-
Datsun 180	3	-	3	3	1
Datsun 240Z	1	-	-	-	-
Datsun 1200	2	-	1	1	-
Honda Accord	1	-	1	1	1
Honda Civic	1	-	1	1	1
Toyota 1000	1	-	1	1	-
Toyota Corona Mk. II	3	-	2	2	1
Toyota Crown	1	-	1	1	-
Toyota Corolla	1	-	1	1	1
TOTAL	96	24	73	97	29