PPAD 9/33/39

Field of vision (A-pillar Geometry) - a review of the needs of drivers

Final report

Prepared for:

The Department of the Environment, Transport and the Regions

Prepared by

Claire Quigley
Sharon Cook
Richard Tait

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Executive Summary

It is the responsibility of the Department of the Environment, Transport and the Regions (DETR) to improve the safety of the UK road network. Driver vision has been identified as a significant factor and the possible causes of reduced vision require further investigation.

This study was commissioned to identify the problems associated with restricted visibility for vehicle drivers, in particular the consequential risk to road safety of changes in A-pillar size and position, driven by the need for improved structural and aerodynamic performance, which can restrict driver vision.

The experimental trials supported the findings of the literature review and the driver survey that A-pillars do impede the driver’s forward field of view. It was shown that:

- Approximately one third of all the targets presented in the vicinity of the A-pillar were not detected.
- A-pillar obscuration is a greater problem in newer, as opposed to older, cars (although this is only statistically significant for viewing past the off-side A-pillar).
- If drivers make the effort to ‘look around’ their A-pillars the visual problems caused by A-pillar obscuration can be significantly reduced. However such a strategy cannot be relied upon and may be unsafe to encourage if the driver should also be concentrating on the road ahead.

The study therefore shows that there are safety disbenefits due to the trend for wider A-pillars. Further research work into A-pillar design should be considered in terms of the drivers’ field of view which may include:

- the use of accident statistics to quantify the effect of A-pillar design on driver vision,
- a study to investigate the relationship between target detection and obscuration angle (ranging from 0° to 6°), this may also include an investigation into the location of the A-pillar in the drivers’ visual field,
- creating awareness amongst interested parties of the visual effects of increased A-pillar thickness.

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1.0 Introduction

It is the responsibility of the Department of the Environment, Transport and the Regions (DETR) to improve the safety of the UK road network. Driver vision has been identified as a significant factor and the possible causes of reduced vision require further investigation.

The objective of the work was to identify the problems associated with restricted visibility for vehicle drivers, in particular "the consequential risk to road safety of changes in A-pillar size and position, driven by the need for improved structural and aerodynamic performance, which can restrict driver vision". The specific areas investigated were:

- the actual differences in A-pillar design between older and newer cars,
- the relative obscuration of off-side and near-side A-pillars in older versus newer cars,
- the ability of drivers to compensate for A-pillar obscuration by looking around them.

2.0 Research review

In addition to the research, a review was undertaken of the directives, regulations and standards pertaining to A-pillar obscuration. A précis of the legislative literature can be found in Appendix 1.

2.1. A-Pillar Obstructions

Along with the rear view mirror, the bonnet and the wings, the A-pillars have been identified as the main obstructions to the visual field from the driver's seat (Allen, 1996). An object on collision course with the vehicle may be obstructed by the A-pillars, causing the object to be overlooked until it is too late to avoid it. Therefore, the design of the A-pillar is an important factor when trying to maximise the drivers' forward field of view.

2.2. Design and measurement of A-pillars

Haslegrave (from Peacock and Karwoski in "Automotive Ergonomics", 1993) discusses binocular vision and how it can have "very little effect on the view of distant objects... but can have a considerable effect on obscuration caused by objects in the near field of view". This can affect the design of A-pillars, because if the width of the A-pillar is less than the width between the eyes, distant objects will be visible, and only a portion of the road directly beyond the pillar will be obscured. Directive 77/649/EEC deals with the binocular obscuration of the A-pillar and takes into account both eye and head turn when assessing the extent of obscuration.

There are a number of techniques which can be used to measure direct field of view. The first involves an observer describing the view while sitting in a vehicle, the second uses a camera instead of an observer placed in the position of the driver's eye, which provides a permanent record. The third technique uses lights to represent the driver's eyes, so wherever an object obstructs the field of view, including the A-pillars, the light is obscured. The area of obscuration of the A-pillars or any other objects can be measured using a reference grid marked on a screen which surrounds the vehicle. An alternative to using this sort of laboratory testing is to use computer based modelling systems, such as SAMMIE (Systems for Aiding Man-Machine Interaction).

It should be remembered that visual requirements must be incorporated with other design necessities. Most importantly, the positioning and thickness of the A-pillars is essential to the mechanical strength of the vehicle as they form part of the cage which protects the vehicle occupants in the incident of impact or rollover. Therefore, visual requirements should be given consideration at the earliest stage possible in the design process, as this will avoid complex modifications later on.

Fowkes (1986) describes the legislation set out for forward field of view in Directive 77/649/EEC. This includes a limit set for the binocular obscuration of each A-pillar, which should not exceed 6^o from two eye points rotated around a simulated neck pivot.

A-pillars have been described as being potentially able to restrict essential visibility of road signs, oncoming vehicles and vulnerable road users during driving (Porter and Stearn, 1986). Therefore, a technique to quantify forward field of view was developed. Participants in a trial evaluating the design of a prototype car, which compared with the designs of four market competitors, were given a SAMMIE generated visibility grid, and were asked to draw on areas which were obscured by objects, such as the A-pillars. Comparisons of all the completed visibility charts from each vehicle, and then from each participant, were undertaken in order to quantify the angle of A-pillar obscuration. The use of this method revealed that the angle of lateral visibility was significantly less in the prototype car. This resulted in the A-pillars of the vehicle in question being moved further around the side of the windscreen and also being reduced in width by removing its thick trim to improve forward visibility.

Fosberry and Mills (1956) measured windscreen pillar obscuration angles in various cars and found a variation from 2^o to 12^o. A comparison of these pillar widths were made with the requirements at the time, which revealed that only five out of the fifteen conformed to the recommended requirements and one failed to comply by a negligible amount.

2.3. The effect of A-pillar design

Bhise (undated) conducted an investigated into the "visual field requirements of vehicles in freeway merging situations", looking at the "search and scan behaviours" of drivers. This found that the A-pillar on the driver's side caused the greater field of impairment and that between 2 and 4% of vehicles were found to be in this obscured area at the time of measurement.

The effect of A-pillars on a driver's field of view is not limited to direct obscuration. Chong and Triggs (1989) investigated the effects of detecting targets when in the vicinity of a window post, such as an A-pillar. It was concluded that visual performance can be influenced in two ways. Firstly, inappropriate visual accommodation towards the post can occur (i.e. vision will be accommodated at the distance of the post rather than the distance of the targets beyond), although this effect can be reduced when the line of gaze is greater than 1^o from the post. Secondly, the presence of a target up to 1-2 degrees from the edge of the post results in them being detected less easily.

A study by Roscoe and Hull (1982, in Chong and Triggs) found that targets were poorly detected when positioned close to the edges of an intervening post and that the detection of distant targets was affected by posts with widths greater than the observers interocular distance.

2.4. Conclusion to the research review

Although an extensive literature review was conducted, no explicit rationale for current levels of visibility were identified.

It appears that, as well as causing direct obscuration of part of a driver's forward field of view, A-pillars interfere with the detection of objects in their close vicinity and could cause inappropriate visual accommodation towards the A-pillar rather than distant objects. As no rationale for current visibility levels was identified, and as from the few studies found, there was an indication that A-pillars do affect the detection of objects in close vicinity, it was decided that further work would be required to investigate the effects of changing A-pillar dimensions on object detection. This would be achieved by undertaking a survey to identify the major differences in A-pillar dimensions between older and newer cars, and undertaking trials to determine the degree to which any changes between older and newer cars has lead to increased obscuration.

3.0 Interviews with drivers

To help ensure that the scope of the testing programme which was planned for Phase 2 of the project addressed all the key issues, a survey was undertaken to seek drivers views on the field of vision through car windows.

Face-to-face interviews were conducted with a random selection of drivers in the Loughborough area to seek information on their experiences of, amongst other aspects, the effects of A-pillar design on visibility.

A copy of the questionnaire (see questions 2.9 to 2.11 for relevant questions) and the data tables are provided in Appendices 2 and 3.

3.1. Car driver experiences and opinions

Interviews were completed with 30 drivers (14 male, 16 female).

Sample details are given in Table 1and Table 2:

Table 1: Age and years of driving

	Age	**Years driving**
Average	42	23
Minimum	21	4
Maximum	72	54

Table 2: Age of vehicle

(Years)	**Age of car**	**How long owned**
Average	7.3	2.9
Minimum	2	0.1
Maximum	15	13

Of the 30 drivers interviewed, 11 said that the A-pillar sometimes or often restricts their vision out of the car and 14 stated that they sometimes or often had to move their head to see round it.

Two drivers reported near misses that they had experienced as a result of A-pillar obscuration. One had experienced a number of near misses at T-junctions in several cars and the other had failed to see an approaching car at a roundabout.

3.2. Conclusion to the interviews

It appears from the responses that A-pillars can restrict drivers' vision out of the vehicle and can potentially cause drivers to detect objects slower than what would otherwise be possible. This in turn could result in an increased possibility of an accident occurring.

The ages of the cars in this small sample means that many of the respondents cars will not have the newer design of A-pillar, which tends to be thicker and more raked. It is therefore difficult to determine from this survey if obstructions to vision caused by A-pillars are worse or better with newer designs. This aspect was addressed in Phase 2 (i.e. the experimental work).

4.0 A-pillar obscuration - Survey of cars

4.1. Aim of the survey

Prior to field of view trials being undertaken, a survey of newer and older cars was conducted to ensure that representative vehicles were used.

4.2. Survey of new cars (including windscreen swept area and rake)

A survey of a sample of new model vehicles was undertaken to determine A-pillar widths, eye-to-A-pillar geometries and the resultant degree of obscuration imposed.

A total of twenty-seven vehicles between 0 and 3 years old were surveyed. They were the most current models from a representative range of classes and makes (see Table 3) many of which had been included in the crash tests carried out by the European New Car Assessment Programme (Euro NCAP).

Table 3: The range of vehicles measured in the survey

Make	Superminis	Small Family Cars	Large Family Cars	Executive Cars	MPV	Other (e.g. Sports, 4WD)
Alpha Romeo			156			
Audi			**A4**	**A6**		
BMW				**5 series**, 7 series		
Citroen		**Xsara**				
Daewoo	Matiz					
Fiat	Seicento					
Ford	Ka	**Focus**	**Mondeo**			
Honda			Accord			
Jaguar						XK8
Jeep						Grand Cherokee
Land Rover						Discovery
Nissan			**Primera**			
Peugeot	206		**406**			
Renault			**Laguna**		**Espace**	
Rover		200				
Seat					Alhambra	
Skoda			Octavia			
Toyota	Yaris					
Vauxhall		**Astra**				
VW			**Passat**			
Volvo			V40			

Those in bold – have featured in the Euro NCAP crash test programme.

4.3. Methodology

To be able to carry out a comprehensive assessment of the variation in A-pillar geometry in new cars, the measurements taken included the dimensions of each A-pillar, their location in relation to the driver's eye point and the ground, the driver's eye point in relation to the ground, and windscreen and A-pillar rake. A full list of the measurements taken and their location can be seen in Table 4, Figure 1 and Figure 2.

Table 4: The measurements taken in each vehicle to assess A-pillar obscuration and rake.

	Measurement description	Location in Figures 1 & 2*
1	A-pillar length	A
2	Distance between A-pillar centre points	
3	Height of A-pillar base above ground	C
4	Height of A-pillar top above ground	D
5	Internal, horizontal obscuration thickness - off-side**	E
6	Internal, horizontal obscuration thickness - near-side**	
7	A-pillar inclination from vertical	F
8	Windscreen inclination from vertical	
9	Seat back angle from vertical	
10	Eye point marker to A-pillar centre point - off-side	G
11	Eye point marker to A-pillar centre point - near-side	H
12	Height of eye point marker above ground	
13	Longitudinal distance from eye-point marker to A-pillar centre	J
14	Lateral distance from eye-point marker to A-pillar centre	K
15	Side window inclination from vertical	
16	Angle of obscuration - off-side (calculated using 5(E) and 10(G), not measured)	L
17	Angle of obscuration - near-side(calculated using 6 and 11(H), not measured)	

* *where relevant.*

** this includes any obscuration band (e.g. black shading) around the edge of the windscreen.

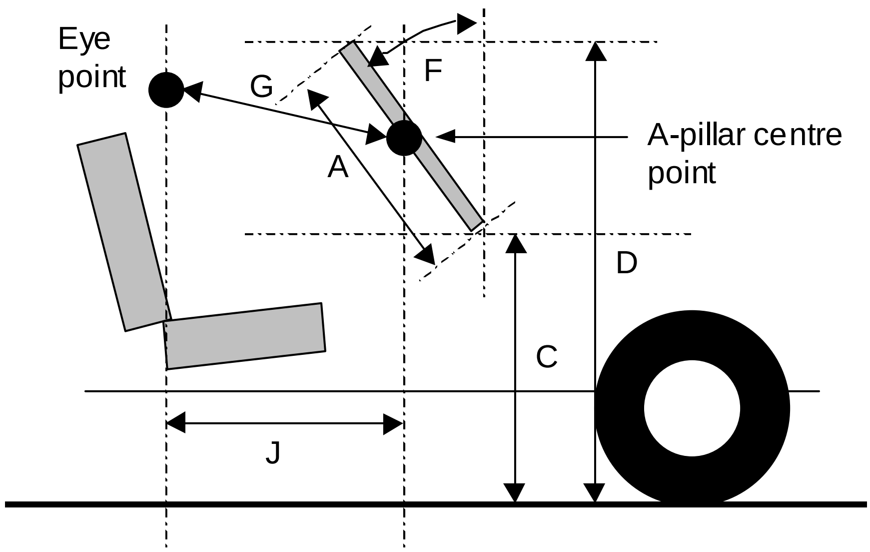


Figure 1: Side elevation showing driver's seat and A-pillar

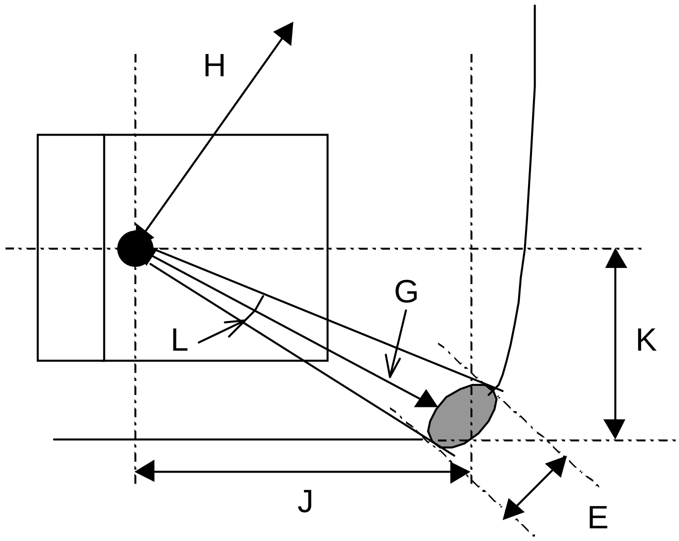


Figure 2: Plan view of drivers seat and off-side A-pillar

For each vehicle, the driver's seat was adjusted to the lowest most rearward position. An SAE H-point manikin (of average adult male height) was used to determine a reference for the eye points as detailed in Directive 77/649/EEC.

Measurements were then taken from which the extent of A-pillar visual obscuration could be calculated. In addition, measurements which could be used to calculate windscreen wiper swept area of each car were recorded and are displayed in Table 5 and Figure 3. The data calculated from these additional measurements are reported in Appendix 4.

Table 5: Windscreen features which were measured for each vehicle to assess the windscreen wiper swept area.

Measurement description	Location in Figure 3*
Depth below windscreen lower edge of wiper drive shaft	L
Distance from windscreen’s off side edge to first wiper drive shaft	M
Distance between wiper drive shafts	N
Distance of second wiper drive shaft from windscreen’s near side	O
Length of off side wiper arm	
Length of near side wiper arm	Q2
Length of off side wiper blade	R1
Length of near side wiper blade	R2
Height of windscreen top edge (centre) above ground	
Height of windscreen bottom edge (centre) above ground	

**where relevant*

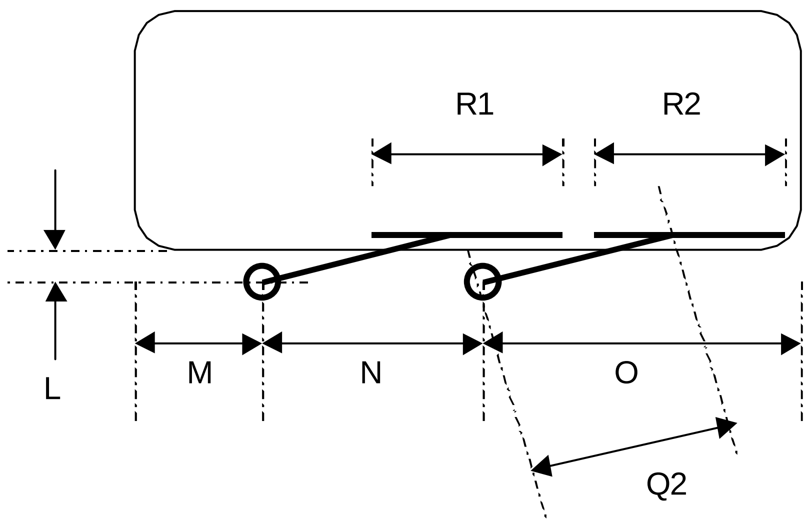


Figure 3: Front elevation showing windscreen and wipers.

4.4. Survey of older cars

In addition, a further survey of 11 cars between 5 and 17 years old (i.e. pre Euro NCAP) was undertaken for A-pillar obscuration only. A list of these cars are displayed in Table 6.

Table 6: The range of vehicles measured in the "older car" survey

Make	Small Cars	Small Family Cars	Family Cars	Executive/Sports Cars
BMW				5 series
Ford		Escort	Mondeo	
Nissan		Sunny		
Peugeot	106		309, 306	
Vauxhall		Astra	Cavalier	
VW		Golf		
Volvo	480 GT			

4.5. Results/findings

The results of the two surveys were used to select cars for the A-pillar obscuration trials and to investigate the changes in A-pillar dimensions in new cars compared to older cars. Table 7 and Table 8 show the summary of the measurements taken which were used to calculate A-pillar obscuration and compare A-pillar designs in older and newer vehicles.

Table 7: The findings of the A-pillar obscuration survey of new cars.

Measurement description	Mean	Minimum	Maximum
A-pillar length, mm	759	600	890
Distance between A-pillar centre points, mm	1298	1145	1565
Internal, horizontal obscuration thickness - off-side, mm	113	85	135
Internal, horizontal obscuration thickness - near-side, mm	140	105	165
A-pillar inclination from vertical, ^{o}	57	40	61
Windscreen inclination from vertical, ^{o}	59	41	63
Eye point marker to A-pillar centre point - off-side, mm	857	727	1126
Eye point marker to A-pillar centre point - near-side, mm	1260	1120	1435
Longitudinal distance from eye-point marker to A-pillar centre, mm	824	695	1100
Lateral distance from eye-point marker to A-pillar centre, mm	292	260	360
Side window inclination from vertical, ^{o}	25	11	35

Table 8: The findings of the A-pillar obscuration survey of older cars.

Measurement description	Mean	Minimum	Maximum
A-pillar length, mm	685	590	805
Distance between A-pillar centre points, mm	1286	1213	1500
Internal, horizontal obscuration thickness - off-side, mm	93	80	104
Internal, horizontal obscuration thickness - near-side, mm	118	95	131
A-pillar inclination from vertical, ^{o}	55	51	59
Windscreen inclination from vertical, ^{o}	57	53	62
Eye point marker to A-pillar centre point - off-side, mm	923	796	1020
Eye point marker to A-pillar centre point - near-side, mm	1245	1175	1365
Longitudinal distance from eye-point marker to A-pillar centre, mm	859	755	952
Lateral distance from eye-point marker to A-pillar centre, mm	278	234	342
Side window inclination from vertical, ^{o}	24	22	30

A statistical comparison[1] of measurements from older cars with new models found that compared to the old cars, newer cars had:

- Significantly longer A-pillars.
- Significantly greater internal horizontal obscuration angles (near and off-side).
- Significantly greater A-pillar and windscreen inclination from vertical.
- Significantly closer A-pillar to eye-point in rear most position (off-side only, direct, longitudinal and lateral).

From the information collected, obscuration angles resulting from both the off-side and near-side A-pillars were calculated using internal obscuration thickness and A-pillar to eye point distance measurements. This included any obscuration band around the edge of the windscreen, in line with the definition given in Directive 77/649/EEC (see Appendix 1). The mean obscuration angle of both off-side and near-side A-pillars was less in older cars than newer cars. This difference was found to be statistically significant, i.e. A-pillar obscuration angles have become significantly worse in newer cars than in older cars. However, it must be

[1]All data, in the survey and in the trials, was tested for statistical significance using both a chi-squared test and a two-tailed, paired t-test at 5% significance. Any apparent differences between conditions which are not significant are due to natural variability in the data and are not due to differences in A-pillar design.

noted that comparisons were not with identical cars, i.e. many of the older cars were not old versions of the new cars.

A list of the cars involved in both surveys was then devised ranging from the car with least obscuration to the car with the most (see Table 9 for full list). It was then decided that the cars with the least, most and mean overall A-pillar obscuration (i.e. the combined off-side and near-side obscuration) would be used in the obscuration trials. Therefore, of the cars in these categories available at the time of the trials, the Nissan Sunny (least), Ford Focus (mean) and Renault Laguna (most) were selected. This also allowed for comparison of older design cars (i.e. Nissan Sunny) with new designs (i.e. Ford Focus, Renault Laguna).

To ensure a representative selection of vehicles were used in the trials, the extent of A-pillar obscuration (as defined in Figure 2) of the vehicles surveyed was ranked. Due to the resource constraints of the study, absolute measures of obscuration using the procedures given in the Council Directive were approximated by a more time efficient monocular method to obtain the rankings. For this reason the angles given in Table 9 are greater than those regulated.

Table 9: The variation in A-pillar obscuration angle from least to most obscuration (as calculated from Table 4 and defined in Figure 2)

	OFF-SIDE		NEAR-SIDE		SUM OF OFF-SIDE AND NEAR-SIDE	
Least	**Sunny**	**5.4**	Discovery	4.4	**Escort**	**10.8**
	A4	5.5	**480 GT**	**4.6**	**Sunny**	**10.9**
	309	**5.8**	**Escort**	**4.7**	A4	11.0
	Espace	6.0	**Cavalier**	**5.0**	**309**	**11.1**
	A6	6.0	**309**	**5.2**	A6	11.5
	Escort	**6.1**	**Mondeo**	**5.4**	**480 GT**	**11.6**
	Astra	**6.1**	A6	5.5	**Astra**	**11.7**
	5 Series	**6.2**	A4	5.5	Discovery	11.8
	309.0	**6.5**	**309.0**	**5.5**	**Cavalier**	**11.8**
	156	6.7	**Sunny**	**5.5**	**309.0**	**12.0**
	Accord	6.7	**Astra**	**5.6**	**5 Series**	**12.2**
	Cavalier	**6.8**	**Golf**	**5.8**	**Mondeo**	**12.4**
	Mondeo	**7.0**	Mondeo	5.8	Espace	12.7
	480 GT	**7.0**	**5 Series**	**5.9**	**Golf**	**12.8**
	523i	7.0	406	6.0	156	12.9
	728i	7.0	523i	6.1	523i	13.0
	Golf	**7.0**	Passat	6.1	Accord	13.1
	Seicento SX	7.1	Focus	6.1	728i	13.2
	Passat	7.1	728i	6.2	Passat	13.2
	Focus	7.2	Primera	6.2	Mondeo	13.3
	Discovery	7.4	156	6.2	Focus	13.4
	Alhambra	7.5	Seicento SX	6.3	Seicento SX	13.4
	Mondeo	7.5	Accord	6.3	Alhambra	13.9
	Astra	7.6	Ka	6.3	Primera	14.2
	206	7.8	Alhambra	6.4	406	14.2
	200	7.8	**306**	**6.4**	**306**	**14.3**
	306	**7.9**	Xsara	6.5	206	14.5
	Octavia	7.9	206	6.7	Ka	14.7
	Primera	8.0	Espace	6.8	200	14.8
	Matiz	8.2	Grand Cherokee	6.8	Octavia	14.8
	406	8.3	Yaris	6.8	Astra	14.8
	V40	8.3	Octavia	6.8	Matiz	15.3
	Ka	8.4	200	6.9	Yaris	15.4
	Yaris	8.5	XK8	7.0	Xsara	15.4
	Laguna	8.7	Astra	7.2	V40	15.5
	XK8	8.8	Matiz	7.2	XK8	15.8
	Xsara	8.9	V40	7.2	Laguna	16.0
Most	Grand Cherokee	9.4	Laguna	7.3	Grand Cherokee	16.2
Mean		**7.3**		**6.1**		**13.4**

Bold = more than five years old Not bold = less than five years old

5.0 A-pillar obscuration trials

Field of view (A-pillar) trials were undertaken to investigate the effect on driver's forward vision of the recent changes in the size and positioning of A-pillars. Concern has been expressed regarding the risk to road safety of these structures in terms of the blind spots they may cause and drivers' ability to compensate for them.

To obtain an overall view of how A-pillar thickness affects the level of driver's obscuration of their forward field of view, a laboratory-based trial was devised. The aim of the trial was to determine the extent to which different angles of A-pillar obscuration affect the detection of targets in the visual field in a number of different driving scenarios.

5.1. Methodology

5.1.1. Equipment/variables

A full-scale, 180^{o} wrap around, panoramic road scene was developed which consisted of enlarged (8' x 4') photographic images of a real road scene (i.e. a busy road junction), as displayed in Figure 4.

Figure 4: View of the road scene

Within an appropriate part of this scene a computer screen was positioned which was to be used for the road sign task in the first part of the trial. This will be explained in more detail later in this section.

Thirty LEDs, which were identical in terms of colour and intensity, were used as the targets for the participants to detect. It was ensured that these lights were conspicuous enough so that the only reason a participant could not see a target was due to it being obscured (i.e. by the A-pillar).

The targets were positioned around the areas in which the A-pillars could have caused an obstruction in all three chosen vehicles and a number were positioned either side of these areas. This also took into account seat positioning. The targets were positioned between 25^o and 65^o to the left of the driver's line of sight and between 15^o and 47^o to the right of the driver's line of sight. In general, they were between 2^o and 5^o apart, although in the critical areas (i.e. where the A-pillar could have caused obstruction) they were positioned no more than 2^o apart. Table 10 and Figure 5 show the position of each target in relation to the driver's line of sight.

The vertical position of the targets also varied, with targets positioned from 5^o below to 3^o above the line of sight of the H-point manikin (this would vary slightly due to the height of each participant but the range of 8^o would remain the same). However, all were in vertical positions where targets in the road scene would be expected to be seen. Figure 6 shows the vehicles used in the trials.

Table 10: The location of the targets in relation to the driver's line of sight.

To the left of driver's line of sight		To the right of driver's line of sight	
Target Number	Angle °	Target Number	Angle °
1	65	15	15
2	63	16	17
3	61	17	19
4	59	18	20
5	57	19	22
6	55	20	24
7	53	21	26
8	50	22	28
9	46	23	30
10	42	24	32
11	38	25	34
12	33	26	36
13	30	27	40
14	25	28	42
		29	44
		30	47

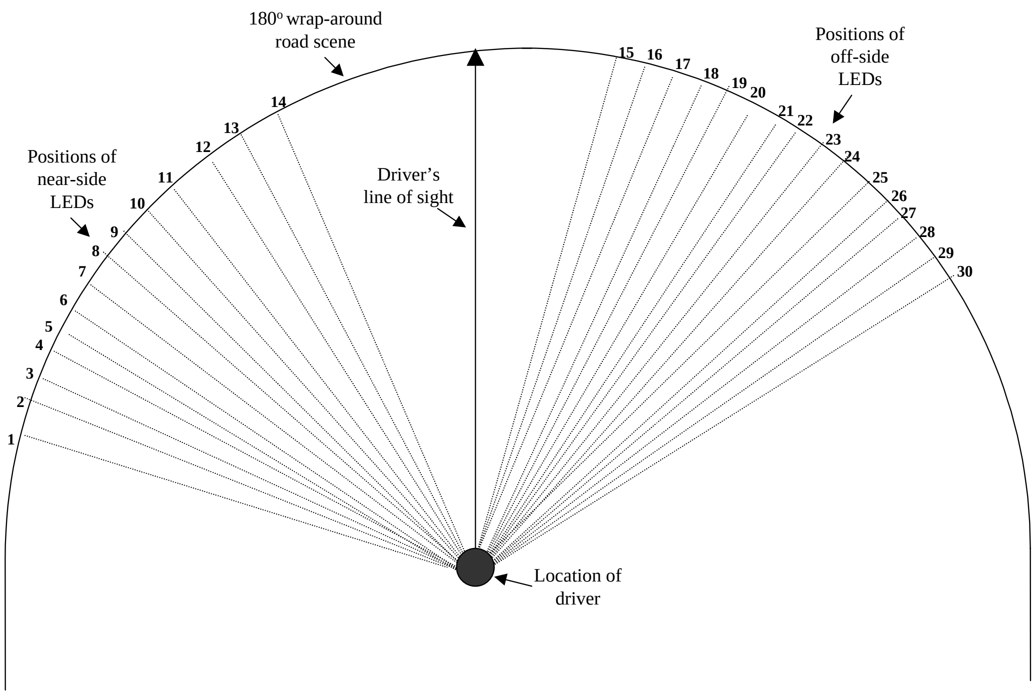
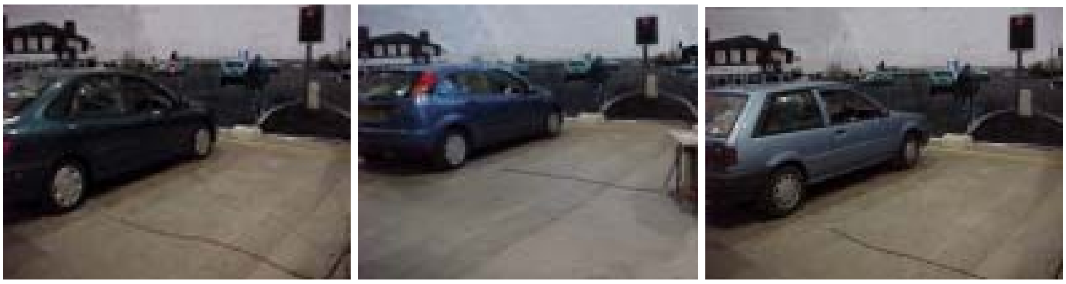


Figure 5: Schematic view of the target locations in the road scene.



(a) Laguna **(b) Focus** **(c) Sunny**

Figure 6 (a) to (c): The cars used in the trials.

5.1.2. Procedure

Task 1

The aim of task 1 was to investigate the effects of A-pillar thickness on the ability to detect nearby hazards when a driver's focus of attention is on the road ahead.

The participant was seated in the first vehicle and was asked to adjust the driving seat to a suitable driving position. The driver's eye point was then approximately aligned to the set eye point position marked out on the floor by pushing the car back or forth.

Once the participant was satisfied with their seat position, they were asked to don their seat belt. Prior to the start of the trial, it was ensured that the participant was familiar with the tasks they were about to carry out by undertaking a practice run. Once they were happy with the procedure, the trial began. At random intervals in a random order, one of the thirty target lights were activated, which triggered the reaction timer (see Figure 7). Once the participant had detected the target, they were required to respond immediately by pressing a button which was attached to the steering wheel in the car, which in turn stopped the timer. The reaction time was then recorded. It was assumed that if the participant had not responded after five seconds, they could not see the target and was recorded as a miss. This was repeated for all 30 targets.

Figure 7: Examples of the target lights.

To make the trial more representative of the driving task, the participants had to undertake a secondary task to prevent them from searching for targets and to keep their concentration on the "road" ahead. This task involved viewing road signs displayed on a screen positioned appropriately within the road scene (see Figure 8). Initially, a prompt screen consisting of one town name was viewed (Figure 8(a)). The participant was then required to look for this town in the following signs which appeared approximately every three seconds. Each sign consisted of a list of five towns which the participant had to check (Figure 8 (b)). If their town was present in the sign they had to use the indicators in the car according to the directional information given beside the town name.

(a) **(b)**

Figure 8 (a) and (b): The road sign task

Task 2

The aim of task 2 was to investigate the effect of A-pillar thickness on the ability of the driver to detect targets when actively searching for them, for example, at a road junction.

As with task 1, each participant was given time to familiarise themselves with the task they were about to undertake and once they were happy to continue, the trial began.

The participant was asked to concentrate on the road ahead. After random intervals, the participant was prompted by the experimenter to search for a target light which would be displayed somewhere on the road scene. However, to guard against false reporting , a target light was only activated on half the occasions a prompt was given and the other half were false alarms (i.e. a prompt was given but no light activated). Once they had decided whether there was a light present or not, they were asked to press the button mounted on the steering wheel and then let the experimenter know whether or not there was a target present by saying Yes or No. The participant’s response and the time from when the experimenter gave the prompt to when the participant pressed the button (i.e. made the decision) was recorded. The task was completed once each of the 30 targets had been displayed and 30 ‘no target’ conditions had been presented in a random order.

The procedures for tasks 1 and 2 were then carried out for cars 2 and 3.

5.1.3. Participants

Twenty current car drivers were invited to participate in the trials. It was ensured that the ratio of male to female participants was approximately 50:50 and the ratio of young to old participants was also 50:50, the age range being between the ages of 21 and 71 years.

5.2. Results/findings

Displayed in Table 11 and Table 12 is the raw data collected from each of the three cars used in the trials. This includes the participants' reaction times to detecting the presence of each target within the road scene and the number of correct target detections.

To determine if differences in A-pillar obscuration angles led to an increased likelihood of targets being obstructed paired two-tailed t-tests and chi-squared tests were carried out.

Table 11: Number of targets undetected in Tasks 1 and 2*.

	Target No.	Number of targets undetected (out of 20) Task 1 Laguna (A1)	Task 1 Sunny (B1)	Task 1 Focus (C1)	Task 2 Laguna (A1)	Task 2 Sunny (B1)	Task 2 Focus (C1)
NEAR SIDE	1	3	1	1	2	0	1
	2	5	0	1	1	0	0
	3	13	8	13	11	5	7
	4	12	11	15	8	8	11
	5	5	9	13	2	5	10
	6	0	3	1	0	0	0
	7	1	1	0	0	0	0
	8	0	1	0	0	0	0
	9	3	4	5	2	0	2
	10	2	3	2	0	0	1
	11	1	3	3	0	1	1
	12	1	2	2	0	0	1
	13	0	1	1	1	0	0
	14	0	0	1	0	0	0
OFF SIDE	15	0	0	0	0	0	0
	16	0	0	0	0	0	1
	17	0	0	0	0	0	0
	18	0	0	0	1	0	0
	19	2	0	1	0	1	0
	20	3	1	4	3	2	0
	21	13	9	12	6	3	5
	22	19	19	17	12	11	11
	23	11	7	10	2	1	2
	24	5	4	9	0	1	1
	25	4	3	6	1	0	0
	26	4	2	3	0	0	0
	27	1	1	2	1	0	0
	28	0	0	0	0	0	0
	29	0	0	1	1	0	0
	30	1	1	1	0	0	0
	Sum	**109**	**94**	**124**	**54**	**38**	**54**

*see section 5.2.1 for description of the shaded and outlined areas

Table 12: Mean detection times of those targets detected in Tasks 1 and 2.

	Target No.	Mean detection time of the targets detected (seconds) Task 1 Laguna (A2)	Task 1 Sunny (B2)	Task 1 Focus (C2)	Task 2 Laguna (A2)	Task 2 Sunny (B2)	Task 2 Focus (C2)
NEAR SIDE	1	0.95	0.88	0.68	1.14	0.82	0.99
	2	0.63	0.65	0.81	1.02	0.81	1.07
	3	1.37	0.79	0.77	1.60	1.49	2.37
	4	1.11	0.80	1.47	1.52	1.55	2.01
	5	0.68	0.83	1.02	0.97	1.32	2.12
	6	0.57	0.57	0.65	0.80	0.61	0.63
	7	0.66	0.73	0.61	0.60	0.58	0.73
	8	0.61	0.71	0.59	0.78	0.68	0.63
	9	0.67	1.13	0.55	0.67	0.80	1.02
	10	0.52	0.55	0.66	0.61	0.63	0.72
	11	0.63	0.97	0.72	0.66	0.81	0.81
	12	0.57	0.79	0.69	0.67	0.69	0.69
	13	0.62	0.52	0.53	0.90	0.68	0.73
	14	0.68	0.69	0.64	0.66	0.71	0.66
OFF SIDE	15	0.54	0.53	0.56	0.67	0.58	0.63
	16	0.57	0.56	0.58	0.69	0.68	0.65
	17	0.52	0.58	0.61	0.67	0.61	0.64
	18	0.60	0.65	0.68	0.81	0.65	0.70
	19	0.73	0.69	0.70	0.88	0.85	0.78
	20	1.06	0.68	0.71	1.13	0.99	1.09
	21	1.40	0.67	1.89	1.50	0.85	1.34
	22	0.53	3.39	0.94	2.17	2.34	2.22
	23	0.59	0.98	0.78	1.39	1.14	1.26
	24	0.95	0.94	0.66	1.14	1.21	1.22
	25	0.96	0.95	0.92	0.82	0.86	0.99
	26	0.86	0.68	0.57	1.03	0.83	0.91
	27	0.92	0.94	0.92	0.93	0.87	1.02
	28	0.78	0.68	0.56	0.76	0.69	0.65
	29	0.66	0.62	0.55	0.82	0.80	1.02
	30	0.67	0.60	0.55	0.88	0.71	0.91
	Mean	**0.75**	**0.82**	**0.75**	**0.96**	**0.89**	**1.04**

5.2.1. Task 1

What effect does A-pillar obscuration have when the drivers' focus of attention is on the road ahead?

Figure 9 shows the main areas in the visual field where target obscuration occurred most frequently. It can be seen that the obscuration areas which are most affected by the A-pillars are:

- Near-side: from 55^o to 65^o (i.e. a range of 10^o) to the left of the driver's line of sight.
- Off-side: from 22^o to 40^o (i.e. a range of 18^o) to the right of the driver's line of sight.

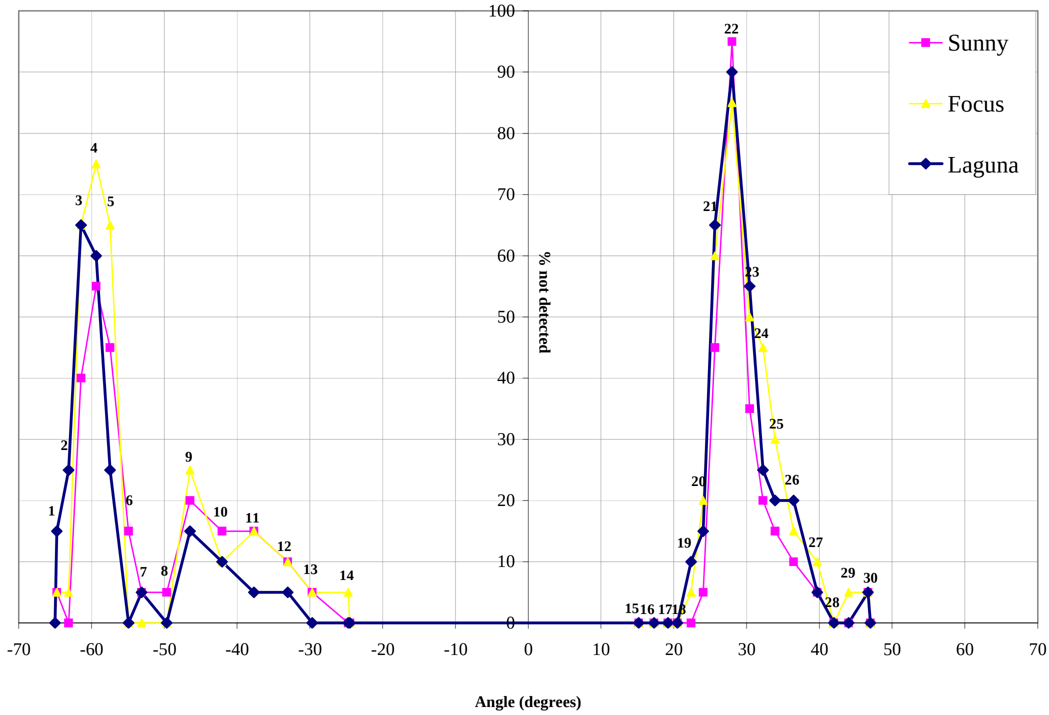


Figure 9: The distribution of target obscuration within the visual field in task 1, where an angle of 0^o refers to the drivers line of sight.

Figure 9 also shows another area on the near-side where targets were being obscured, between 25^o and 46^o (i.e. a range of 21^o).

It was concluded that this was an effect of the internal rear view mirror on some drivers' ability to see targets within this area, particularly those participants with greater sitting heights. Therefore, in order to obtain the rate of obscuration caused by the A-pillars alone, only the targets which were affected by A-pillar obscuration were included in the analysis. These were targets 1 to 6 on the near-side and targets 19 to 27 on the off-side (see also areas outlined in Table 11).

Figure 10 shows the location of the near-side and off-side obscuration areas (i.e. where a target was obscured more than once) in each of the three cars, in relation to the thirty targets (see also all shaded areas in Table 11).

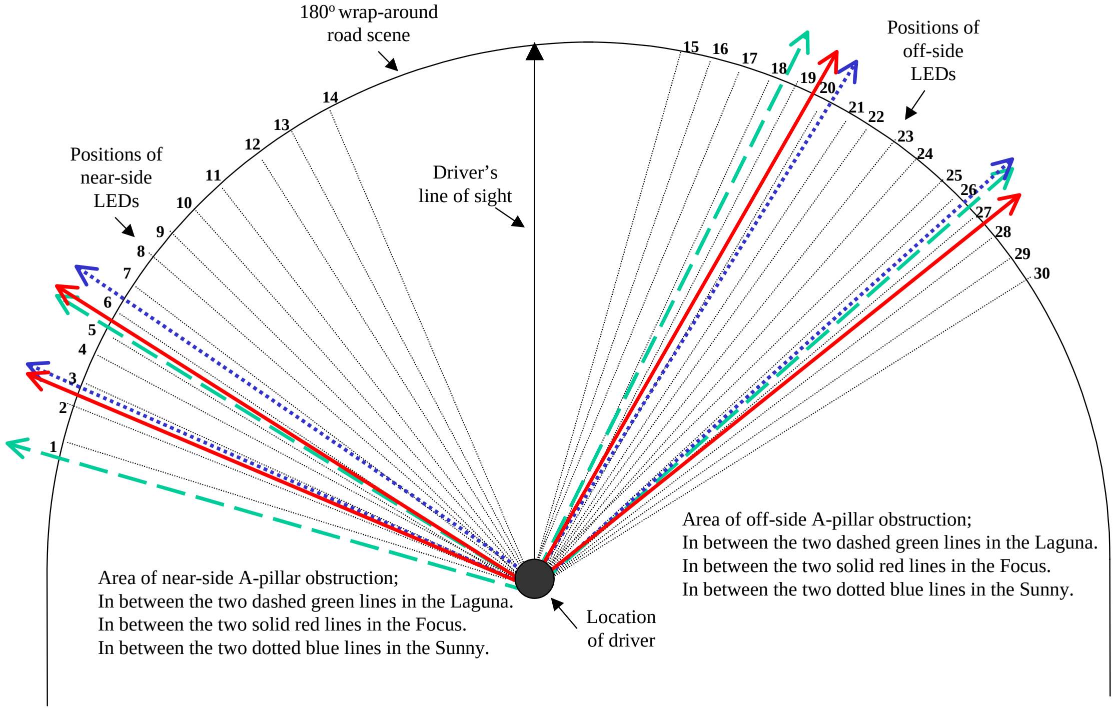


Figure 10: The location of the obscuration areas in each car in relation to the targets

A statistical comparison of the obscuration rate for each target revealed a number of areas in the field of view which were significantly more obscured. These are displayed in Table 13 and are defined as being areas which contained targets that were obscured significantly more often than at least one of the other targets in the A-pillar obscuration area, i.e. targets 1 to 6 on the near-side and 19 to 27 on the off-side (see also the dark shaded areas in Table 11).

Table 13: The areas of significantly high obscuration in the field of view

	Near-side	Off-side
Laguna	$59^o - 61^o$ (targets 4 to 3)	$26^o - 30^o$ (targets 21 to 23)
Focus	$57^o - 61^o$ (targets 5 to 3)	$26^o - 32^o$ (targets 21 to 24)
Sunny	$57^o - 61^o$ (targets 5 to 3)	$26^o - 28^o$ (targets 21 to 22)

What was the rate of A-pillar obscuration in each car?

Table 14 displays the rate of A-pillar obscuration in each car.

Table 14: The percentage of targets obscured in each car by off and near-side A-pillars

	Near-side	Off-side
Laguna	32%	34%
Focus	37%	36%
Sunny	27%	26%

Does an increase in A-pillar thickness lead to increased obscuration and if so, is the increase significant?

Figure 11 shows how A-pillar thickness correlated with obscuration rate (off-side and near side).

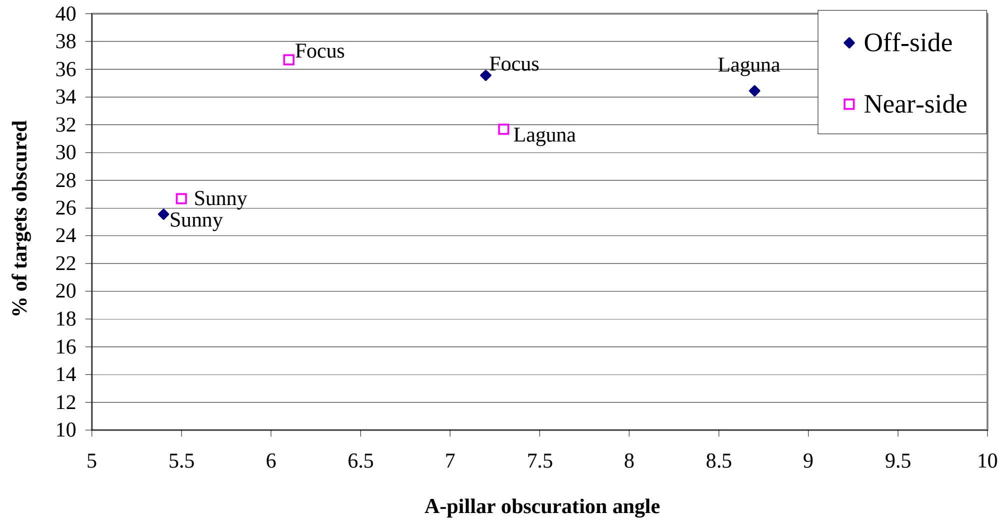


Figure 11: The correlation of A-pillar obscuration angle with level of target obscuration (as calculated from Table 4 and defined in Figure 2).

On the off-side, an A-pillar obscuration angle of 5.4^{o} (Sunny) resulted in significantly less obscuration than angles of 7.2^{o} (Focus) and 8.7^{o} (Laguna). No significant difference in rate of obscuration was found between angles of 7.2^{o} and 8.7^{o}.

On the near-side, an A-pillar obscuration angle of 5.5^{o} (Sunny) resulted in less obscuration than angles of 6.1^{o} (Focus) and 7.3^{o} (Laguna), but this decrease was not statistically significant.

Do the A-pillars on newer cars lead to greater obscuration than those on older models and if so, is this significant?

When comparing obscuration rate in older cars compared to new, it was found that the off-side A-pillars in the new cars led to significantly greater obscuration than the off-side A-pillar in the older car. No statistically significant difference was found between new and older cars when comparing near-side obscuration rates.

5.2.2. Task 2

When asked to search for targets, (i.e. look around the A-pillars in Task 2) is the level of obscuration significantly reduced for each car?

Figure 12 shows the main areas in the visual field where target obscuration occurred most frequently during the search task.

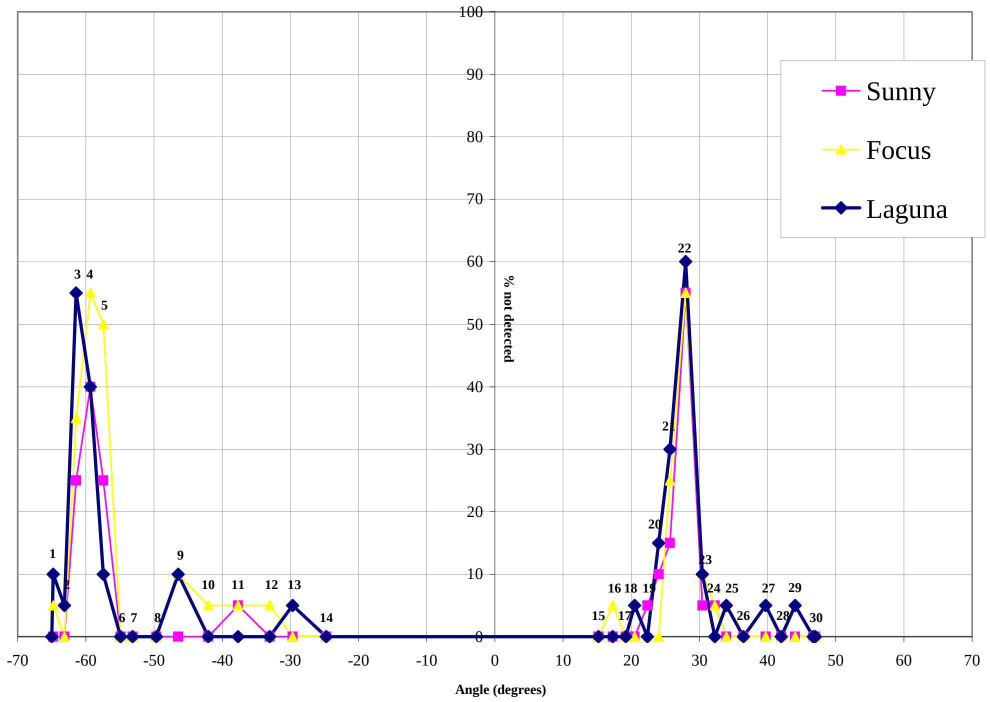


Figure 12: The distribution of target obscuration within the visual field in task 2, where an angle of 0^{o} is refers to the drivers line of sight.

On both the off-side and near-side, the number of obscured targets is significantly reduced in all cars when participants carry out the search task (task 2), as opposed to carrying out the detection task (task 1) (see Figure 9).

As with the first task, the least number of targets were obscured by the off-side and near-side A-pillars in the Sunny.

In terms of reaction time, the participants were, on average able to detect the targets quicker on both the off-side and near side in the Sunny. However, this was only significant on the near-side, where the mean target time was significantly quicker for the Sunny than for the Focus.

6.0 Discussion and conclusions

The conclusion to both the literature review and driver survey, that A-pillars impede the forward field of view, was verified by the trials which were conducted by ICE Ergonomics.

In addition to confirming the detriment to forward vision, the trials also enabled the following quantitative evaluations to be made:

6.1. Changes in A-pillar design

Obscuration angles were simulated, but no evidence was found to suggest that vehicles included in the survey exceeded the regulations. The survey confirmed significant differences in A-pillar design between older and newer cars, namely that newer cars had: longer A-pillars; greater internal horizontal obscuration angles (including obscuration band); greater A-pillar and windscreen inclination from vertical and closer A-pillar to eye-point distances.

6.2. Extent of obstruction to forward visibility

Approximately one third of all the targets presented in the vicinity of the A-pillar were not detected. (This varied from 27% to 37% dependent upon the type of car and the near-side/off-side location).

6.3. Comparative performance of older and newer vehicles

Significantly more targets were seen in the vicinity of the off-side A-pillar for the older car (74%) compared to the two newer cars (64% and 66%). The same effect was noted for the near-side A-pillar although this was not statistically significant. These results would therefore imply that older vehicle designs are less likely to be involved in accidents where A-pillar obscuration is a contributory factor.

6.4. Compensation of A-pillar obscuration by driver behaviour

The likelihood of seeing a target in the vicinity of both the near-side and off-side A-pillars was significantly improved when drivers made the effort to look around them. (This can be seen by a comparison of Figure 9 and Figure 12). However it is inadvisable to rely on this behaviour to compensate for poor forward visibility since:

- Even if driver training schemes were established to educate and encourage such behaviour it cannot be assumed that all drivers will comply in this way all the time,
- It may also be the case that such behaviour may result in more accidents on the road. Whilst it is appropriate to engage in actively searching for potential hazards (targets) in the vicinity of the A-pillar at junctions, it would not be prudent to do this to the same extent when travelling along a road since the driver also needs to give attention to scene ahead. Since drivers are therefore less able to spend time compensating for the A-pillar whilst driving, hazard detection in the drivers peripheral vision is likely to be improved by a reduction in the obscuration imposed by A-pillars.

7.0 Recommendations

7.1. A-pillar design

The results of comparing the off-side field of vision between older and newer cars indicate that there are advantages, in terms of improved detection rates, to using A-pillars which impose smaller angles of obscuration. It is therefore recommended that obscuration angles are kept to a minimum.

7.2. Future work

In the absence of accident data which can be reliably related to A-pillar obscuration as a causal factor, the monetary costs of injuries incurred cannot be related to changes in A-pillar design. Without such quantification it is difficult to specify what level of A-pillar obscuration, and resultant risk to road safety, is acceptable. Consideration should therefore be given to recording A-pillar geometry when carrying out On-the-Spot accident studies and STATS19 data.

However further work should aim to quantify the relationship between A-pillar geometry and object detection. One possible step towards this would be to plot for each angle of obscuration between 0° and 6°, the corresponding likelihood of non-detection of a target in the A-pillar vicinity. The information, which would be obtained from such a study concerning the relative increases in non-detection with increasing obscuration angle, may provide some indication as to an acceptable limit.

In addition, such a study could include analysis, not just of the degree of obscuration, but where that obscuration occurs in the visual field i.e. where is it best to locate A-pillars in the drivers' visual field. Information from accident data would be beneficial in this respect.

It may also be of value to advise drivers, particularly those who are updating their vehicles to newer version of the model they currently drive, that their vision particularly to the off-side may be affected. It may also be useful to make manufacturers aware of the vision implications of increased A-pillar thickness.

8.0 References

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Appendix 1: Directives, Regulations and Standards (A-pillar obscuration)

The following section is a précis of the legislative literature pertaining to A-pillar obscuration. It pays particular reference to the visual properties required and the processes of approval testing.

1.1 Council Directive 77/649/EEC (as amended by 81/643/EEC, 88/366/EEC and 90/630/EEC)

1.1.1 Scope

'. . . applies to the 180° forward field of vision of the drivers of vehicles in category M_1'. Category M_1 is defined as "Motor Vehicles with at least four wheels used for the carriage of passengers and comprising no more than eight seats in addition to the drivers seat".

1.1.2 General specification

No vehicle shall have more than two A-pillars.

The angle of binocular obstruction of each A-pillar shall not exceed 6° (Figure 1).

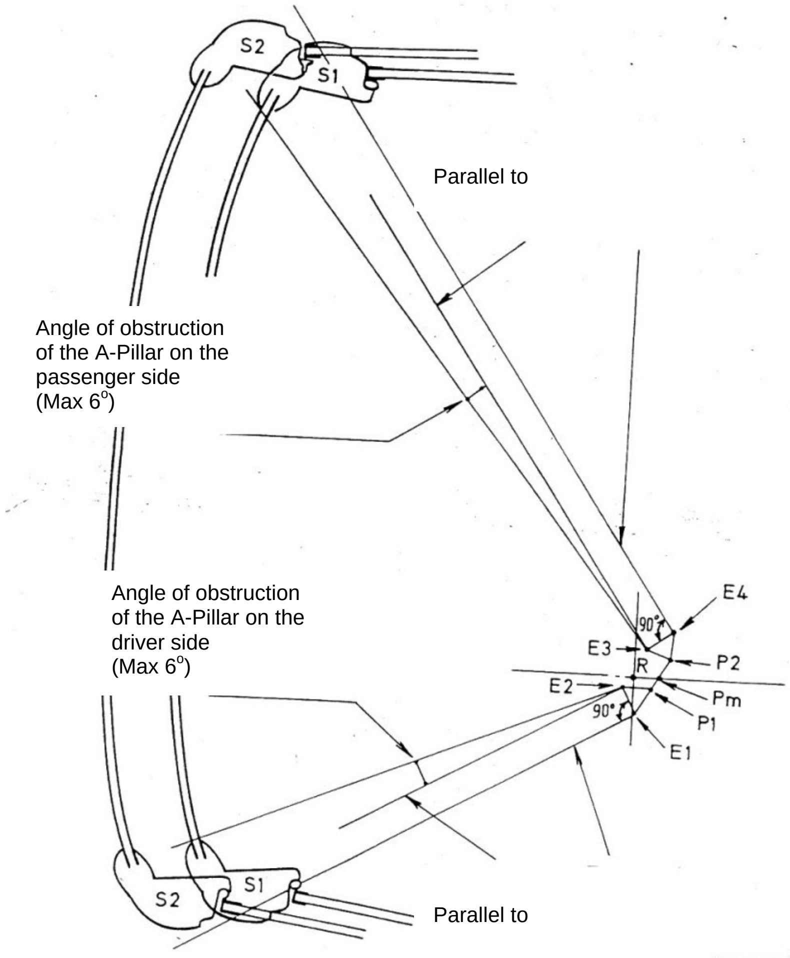

Figure 1: Pillar obstruction

There shall be no obstructions, other than those created by A-pillars and/or vent window division bars, rear-view mirrors and windscreen wipers, in the driver's 180° forward direct field of vision below a horizontal plane through V_1 and above three planes through V_2, one being perpendicular to the plane X-Z and declining forward 4° below the horizontal and the other two being perpendicular to the plane Y-Z and declining 4° below the horizontal. (Figure 2).

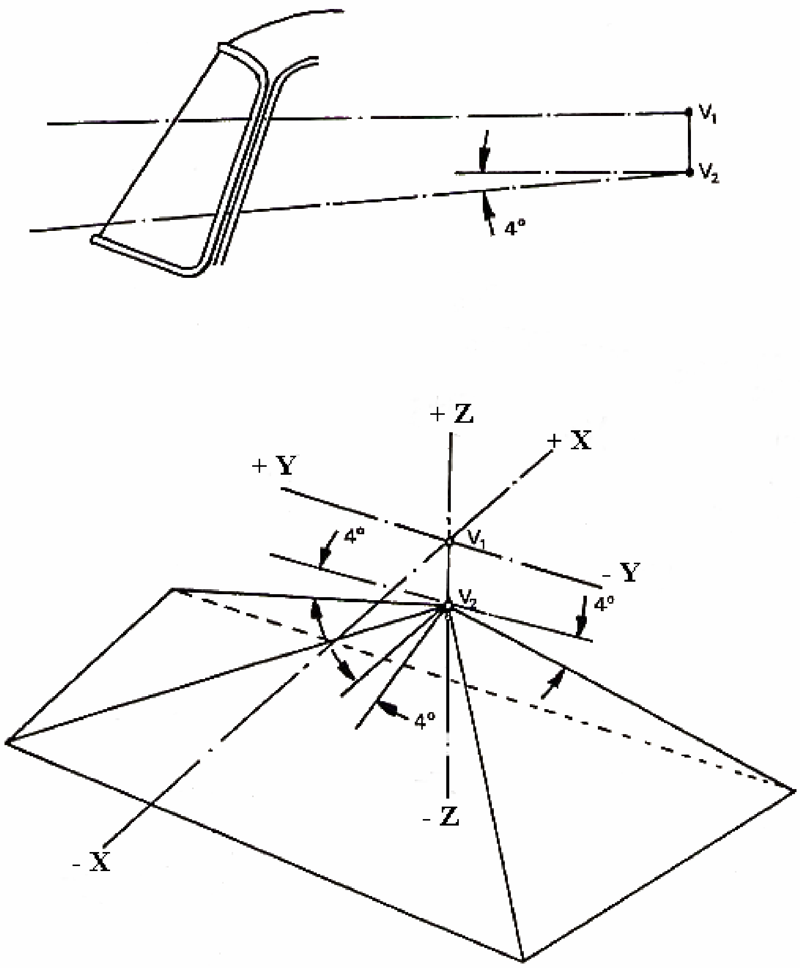

Figure 2: Evaluation of obstructions in the 180° forward direct field of vision of the driver

1.1.3 Definitions

A-pillar:- means any roof support forward of the vertical transverse plane located 68mm in front of the V points and includes non-transparent items, such as windscreen mouldings and door frames, attached or contiguous to such a support.

Primary reference marks:- are defined as ‘holes, surfaces, marks and identification signs on the vehicle body which may be the control points used for body-assembly purposes.’

R-point (seating reference point):- defined by the vehicle manufacturer relative to primary reference marks and:

- has co-ordinates determined in relation to the vehicle structure;
- is the theoretical position of the point of torso/thighs rotation (H-point) for the lowest most rearward normal driving position.

H-point:- is the intersection, in a longitudinal vertical plane, of the theoretical axis of rotation between the thighs and torso of a human body which indicates the position of a seated occupant in the passenger compartment.

Three-dimensional reference grid:- is a reference system which consists of a:

- Vertical longitudinal plane X-Z (+ve X to rear; -ve X to front)
- Horizontal plane X-Y (+ve Y to right; -ve Y to left)
- Vertical transverse plane Y-Z (+ve Z up; -ve Z down)

P-points:- are points about which the driver’s head rotates when he views objects on a horizontal plane at eye level. Two P-points, P_1 and $P_{2,}$ are defined which account for some relative movement of the torso as the head is rotated.
P_1 and P_2 are positioned relative to the R-point using the three-dimensional grid references. The P_m point is the point of intersection between the straight line P_1 and $P_{2,}$ and the longitudinal vertical plane passing through the R point.

Table 1: Drivers head rotation point (P) relative to vehicle's 'R' point

P-point	X	Y	Z
P_1	+35mm	-20mm	+627mm
P_2	+63mm	+ 47mm	+627mm
P_m	+43.36mm	0mm	+627mm

E-points:- correspond to the driver's eye position, e.g. E_1 and E_2 are 65mm apart and are 104 mm from P_1 (see figure 3).

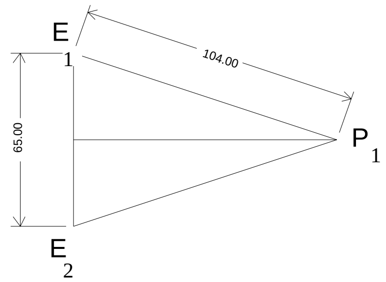

Figure 3: Distance of eye points (E1 & E2) relative to head rotation point (P)

V points are points whose position in the passenger compartment is determined as a function of vertical longitudinal planes passing through the centres of the outermost designated seating positions on the front seat and in relation to the R point.

Appendix 2: Car Driver's Questionnaire

2.1. Introduction:

Hello, I am from Loughborough University and we are undertaking research into drivers' visibility from cars. Can you spare a few moments while we ask you some brief questions about your car?

This is non-judgemental: there are no right or wrong answers we simply want your real opinions and experiences. All information is confidential. We will not reveal the answers in any way in which you will be identifiable.

2.2. What make and model of car do you normally drive?

Make: ______________________ Model: __________________________

Year or Reg letter:_______ How long owned _________ yrs

Approximate annual mileage _______miles

2.2.1. Have you ever had a new windscreen fitted?

Yes how long ago ______ yrs

No

2.2.2. Does mist on the inside of your windscreen ever reduce your vision outside the car?

Often sometimes rarely never *(go to 2.3)*

2.2.3. Under what circumstances?

Comments

2.2.4. How do you clear it?

Fan/heater cloth hand Other (specify)

2.2.5. Do you ever have to clear it while driving?

Often sometimes rarely never

Comments

2.3. When did you last clean the inside of your windscreen of accumulated dirt?

Within the last week

Within the last month

Within the last three months

More than three months ago

Comments

2.4. Do you clean the inside of your windows routinely or just when you notice they are dirty?

Routinely When dirty

2.5. Have you ever experienced problems with vision because of accumulated dirt on the inside of your windows (e.g. due to dazzle from headlights at night)?

Often sometimes rarely never

Comments e.g. vision problems experienced

2.6. Do you ever experience problems driving in bright sunlight?

Often sometimes rarely never (*go to 2.8)*

Comments e.g. vision problems experienced

2.6.1 If yes, what do you do about it?

Comments

2.7. Have you had any accidents or near misses because of glare or dazzle from bright sunlight?

Yes

No

Specify/comments

2.8. Are any of the windows in your car tinted?

Yes *specify (which windows, degree & colour of tint if known)*

No (*go to 2.8.4)*

Comments

2.8.1. If yes, were they tinted when you acquired the car?

Yes

No *(go to 2.8.3)*

2.8.2. Did it influence your purchase decision?

Yes (positively? – explain below)

No

Comments

Now go to 2.9

2.8.3. Why did you have the windows tinted?

Comments

Now go to 1.9

2.8.4. Ignoring the cost, would you consider having tinted windows in your car?

Yes Which windows?

No

Why?/comments

2.9. Thinking now about the pillars at the side of the windscreen in your car (A-pillars). Would you say that they ever restrict your vision out of the car?

Often sometimes rarely never

Specify/comments (PROBE frequency and circumstances)

2.9.1. Are you aware of ever having to move your head to be able to see around the pillar?

Often sometimes rarely never

Specify/comments (PROBE frequency and circumstances)

2.10. How does this pillar compare to other cars you have driven in terms of its effects on visibility?

Same Better Worse

Specify/comments

2.11. Have you had any accidents or near misses because of objects being obscured by this pillar?

Yes

No

Specify/comments

2.12. Respondent details

Year of Birth: ___/___/99 Sex: M / F Years driving: _______yrs

Interview conducted by________________________ Date____/____/ 99

Appendix 3: Driver vision questionnaire data (relevant to A-pillar obscuration)

Interview sample:

Total sample size = 30 , (14 male, 16 female)

3.1 Age of current vehicle

Years	**Age of car**	**How long owned**
Average	7	2.9
Minimum	2	0.1
Maximum	15	13.0

3.2 Age of driver and years of driving

Years	**Age**	**Years driving**
Average	42	23
Minimum	21	4
Maximum	72	54

3.3 Thinking now about the pillars at the side of the windscreen in your car (A-pillars). Would you say that they ever restrict your vision out of the car?

never	13
rarely	5
sometimes	7
often	4

Comments:

-	Turning 90 degrees onto other road
-	Roundabouts
-	Punto always restricted vision - Ford Escort at roundabouts cause problems
-	Tight T junctions, when leaning forward to see
-	Turning right at T junctions, leaning forward, small angle to see left between tax stickers, pillar and rear-view mirror
-	Quite narrow
-	Turning onto major road
-	Are very thin on this car
-	Turning right
-	Back ones more of a problem
-	90 degree turns, pulling out onto dual carriageways off slip roads
-	Two cars approaching junction - one obscured, and roundabouts
-	Looking right for 90 degree junction
-	Reversing into spaces - difficult judge where sides are
-	Roundabouts or corners
-	Twisty bends

3.4 Are you aware of ever having to move your head to be able to see around the pillar?

never	11
rarely	4
sometimes	10
often	4

Comments:

- Roundabouts & reversing
- When peering round 90 degree turns
- Roundabouts
- Sit back and look through side window instead
- A little bit, when turning
- Will do at some point
- Might do but unaware
- As previous plus when parking
- Have learnt to do it . Saab was worst car for it
- Parking
- Twisty bends
- Sign posts when stationery

3.5 How does this pillar compare to other cars you have driven in terms of its effects on visibility?

same	10
better	8
worse	5

Comments:

-	Better than older Polo
-	Worse than mini, better than Punto
-	Similar
-	Later versions of same car were improved. Other Volvos also better
-	Narrower than newer cars driven
-	Better than older cars
-	Never really noticed
-	Better than Ford Mondeo
-	Worse than small cars - Nova
-	No difference
-	Better than Saab
-	Better than Nissan Micra
-	Never really been a problem
-	Mazda about average. Saab was worse
-	Worse than Toyota Starlet
-	Is wider than Escort
-	Same as other Rovers, better than some others
-	Only ever had Renault

3.6 Have you had any accidents or near misses because of things being obscured by this pillar?

Yes	2
No	27

Comments:

-	Approaching T junction 3 or 4 near misses over the years (various cars)
-	Near miss, roundabouts, didn't see car

Appendix 4: Survey of windscreen swept area

4.1 Introduction

The project entitled 'Quality and field of vision' (PPAD 9/33/39) undertaken for DETR required that the effect of A-pillar thickness on driver vision be investigated. In order that a range of vehicles representing the different levels of A-pillar thickness could be used in the experimental work, a survey of vehicles was first undertaken.

Whilst the focus of the survey was to measure A-pillar thickness and the driver's seated position in order to calculate the visual angle obscured, a request was made by the client for further information to be collected at the same time. The additional information collected related to the area of the windscreen swept by the window wipers. This report details the information obtained from this aspect of the survey.

4.2 Survey details

4.2.1 Vehicles surveyed

A total of twenty seven vehicles were surveyed and these are detailed in table 1. The cars were selected for inclusion in the survey according to their popularity on the road. This was estimated from sources such as the NCAP testing programme and surveys undertaken by What Car?

4.2.2 Measurements taken

In addition to the features shown in figure 1 below, values for the windscreen inclination from vertical and the height of the upper and lower edges of the windscreen above the ground, were also collected. These are all given in table 1.

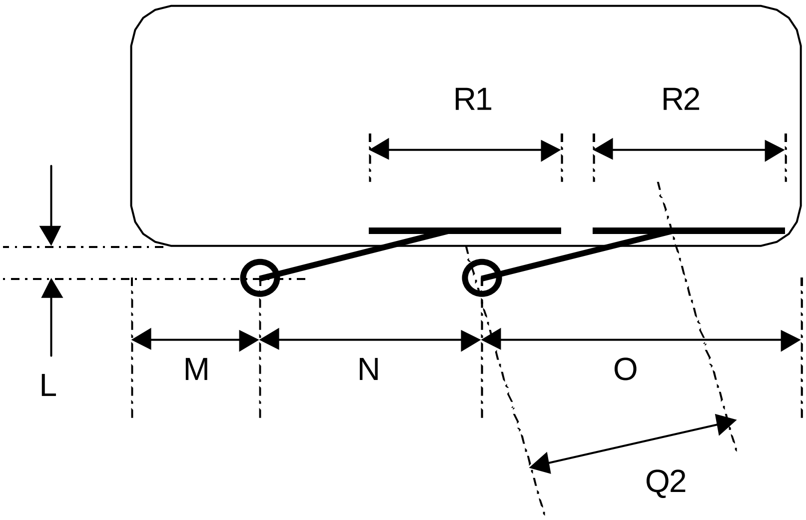

Figure 1: Features surveyed to calculate swept area of windscreen

4.3 Survey results

The raw data from the survey is given in table 2 overleaf. A statistical summary for each feature measured, in terms of minimum, mean and maximum values, is given in table 1.

Table 1: Minimum, mean and maximum values for each feature.

Feature	Minimum	Mean	Maximum
Depth below windscreen lower edge of wiper drive shaft **L**	50	83	165
Distance from windscreen's off side edge to first wiper drive shaft **M**	22	173	845
Distance between wiper drive shafts **N**	400	558	1250
Distance of second wiper drive shaft from windscreen's near side **O**	130	746	1030
Length of off side wiper arm **Q1**	425	544	840
Length of near side wiper arm **Q2**	455	598	895
Length of off side wiper blade **R1**	460	549	705
Length of near side wiper blade **R2**	355	511	705
Windscreen inclination from vertical	27	31	49
Height of windscreen top edge (centre) above ground	1214	1375	1652
Height of windscreen bottom edge (centre) above ground	615	955	1210

Table 2: Windscreen swept area – raw data from survey

Car Number	1	2	3	4	5	6	7	8	9	10
Make	Audi	Alpha Romeo	Audi	Jeep	Honda	Land Rover	Jaguar	BMW	Fiat	Peugeot
Model	A4	156	A6	rand Cheroke	Accord	Discovery	XK8	728i	Seicento SX	406
Year/ Registration	T	T	T	T	V	S	T	T	T	T
Depth below windscreen lower edge of wiper drive shaft **L**	55	60	75	120	65	105	126	165	50	50
Distance from windscreen's off side edge to first wiper drive shaft **M**	113	135	90	140	85	240	60	845	115	125
Distance between wiper drive shafts **N**	555	510	560	670	496	655	660	570	500	545
Distance of second wiper drive shaft from windscreen's near side **O**	820	860	855	820	880	680	830	220	890	890
Length of off side wiper arm **Q1**	518	500	560	490	548	460	485	600	425	510
Length of near side wiper arm **Q2**	558	560	580	510	623	465	530	580	455	600
Length of off side wiper blade **R1**	550	530	570	525	560	520	530	635	480	610
Length of near side wiper blade **R2**	528	535	540	525	481	520	530	560	482	551
Windscreen inclination from vertical	27	28	29	33	29	49	27	31	34	29
Height of windscreen top edge (centre) above ground	1324	1335	1331	1602	1320	1652	1214	1347	1328	1344
Height of windscreen bottom edge (centre) above ground	615	930	935	1200	910	1210	900	890	948	968

Car Number	11	12	13	14	15	16	17	18	19	20
Make	Renault	Nissan	Renault	Toyota	Ford	Skoda	Peugeot	Vauxhall	Seat	Daewoo
Model	Laguna	Primera	Espace	Yaris	Ka	Octavia	206	Astra	Alhambra	Matiz
Year/ Registration	V	T	T	T	V	V	V	S	V	V
Depth below windscreen lower edge of wiper drive shaft **L**	75	100	75	70	75	75	65	82	115	75
Distance from windscreen's off side edge to first wiper drive shaft **M**	22	70	110	100	90	80	685	100	108	100
Distance between wiper drive shafts **N**	520	600	440	400	470	500	435	502	1250	402
Distance of second wiper drive shaft from windscreen's near side **O**	890	762	1030	890	750	905	180	808	222	810
Length of off side wiper arm **Q1**	610	521	605	560	470	498	650	560	840	485
Length of near side wiper arm **Q2**	855	510	820	652	510	682	590	586	565	600
Length of off side wiper blade **R1**	610	530	652	530	480	530	480	506	705	525
Length of near side wiper blade **R2**	455	503	450	355	425	481	660	478	705	400
Windscreen inclination from vertical	28	30	30	31	31	31	28	28	30	31
Height of windscreen top edge (centre) above ground	1340	1308	1560	1412	1323	1363	1331	1325	1592	1405
Height of windscreen bottom edge (centre) above ground	935	930	1090	985	964	945	925	945	1088	968

Car Number	21	22	23	24	25	26	27
Make	Citroen	VW	BMW	Rover	Volvo	Ford	Ford
Model	Xsara	Passat	523i	200	V40	Mondeo	Focus
Year/ Registration	T	T	T	S	S	P	T
Depth below windscreen lower edge of wiper drive shaft **L**	50	70	80	95	85	75	110
Distance from windscreen's off side edge to first wiper drive shaft **M**	110	65	610	125	100	130	130
Distance between wiper drive shafts **N**	510	560	650	600	540	480	475
Distance of second wiper drive shaft from windscreen's near side **O**	800	810	130	804	810	905	890
Length of off side wiper arm **Q1**	480	510	580	550	540	560	570
Length of near side wiper arm **Q2**	550	500	620	530	560	670	895
Length of off side wiper blade **R1**	555	530	570	460	550	540	550
Length of near side wiper blade **R2**	502	530	660	460	500	500	475
Windscreen inclination from vertical	31	30	31	32	29	30	30
Height of windscreen top edge (centre) above ground	1328	1350	1372	1330	1295	1320	1385
Height of windscreen bottom edge (centre) above ground	939	970	945	915	953	816	965