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**George Platzer**  
Consultant

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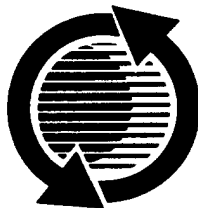
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# The Geometry of Automotive Rearview Mirrors - Why Blind Zones Exist and Strategies to Overcome Them

George Platzer  
Consultant

## ABSTRACT

Equations are derived which describe and relate the magnification, viewing angle and reflected illuminance of convex mirrors as used in automotive applications. The derived equations are compared to those for plane mirrors. Using these equations, the viewing angles of automotive rearview mirrors are calculated and depicted. The blind zones are defined in terms of the viewing angles, obstructions to vision, perceptibility limitations, and the lateral separation of vehicles. Various strategies for overcoming the blind zones are discussed.

## INTRODUCTION

The blind zones produced by automotive rearview mirrors have long been of concern. A variety of ways of coping with them are in use, and new ways are being proposed. Blind zones are an important factor in accidents caused by lane changing maneuvers. The National Highway Traffic Safety Administration (NHTSA) Crash Avoidance Research Program has targeted Lane Change/Merge (LCM) crashes as one of five categories of crashes potentially suitable for high technology Intelligent Vehicle Highway System (IVHS) crash avoidance countermeasures (Knipling, 1993). Wang and Knipling (1994) estimate that LCM crashes account for 4.0% of passenger car crashes, 225 fatalities and 630,000 crashes annually. About 50% of these occur on urban divided highways, and about 75% occur during daylight hours. Involvement by direction of lane change is about equally split between right to left and left to right changes. An analysis of LCM crashes by Najm et. al., 1994 shows that in 61.2% of crashes, the driver did not see the other vehicle. In 29.9% of crashes, the driver misjudged the position and/or speed of the other vehicle.

Mirror blind zones are not responsible for all of the LCM type crashes. However, they are extremely important in that they are not well understood by the average driver, and yet they are an integral part of the data acquisition system used by drivers in LCM maneuvers. Understanding the blind zones

is important, and key elements in understanding them are the viewing angles of the mirrors and where the views are directed.

Equations will be derived which quantify the viewing angles in terms of the relevant parameters. Much of the derivations are by way of review, but some new relationships are shown. Graphical methods can be used to show viewing angles, but analytical methods bring out insights not obtainable graphically. Hence the analytical approach.

The derived equations are next used to calculate the viewing angles of the mirrors on a vehicle using their dimensions and their positions relative to the driver. Then the blind zones are defined and depicted. Several factors in addition to the viewing angles determine the extent of the blind zones, including obstructions to vision due to the vehicle, the driver's ability to perceive objects in both the mirror and his or her peripheral vision, and the lateral separation of the vehicles on the roadway.

Once the blind zones have been established, various strategies which have been developed to overcome the blind zones will be reviewed.

## GEOMETRY OF REARVIEW MIRRORS

On US passenger cars, the inside mirror and left outside mirror are plane, and the right outside mirror is convex. Europe and Japan allow the use of convex mirrors on the driver's side. Since a plane mirror is a special case of a convex mirror with an infinite radius, the convex mirror equations will be derived first.

The spherical convex mirror presents an image at a magnification less than unity. Most introductory physics books give the equations relating the mirror radius, the object distance, the image distance and the magnification. For the spherical convex mirror of Figure 1, it is easily shown that;

$$\frac{1}{-p} + \frac{1}{-q} = \frac{2}{r} = \frac{1}{f} \quad \text{EQ(1)}$$

and,

$$m = \frac{q}{p}, \quad \text{EQ(2)}$$

where,  $p$  = distance of the object from the mirror  
 $q$  = distance of the image from the mirror  
 $r$  = radius of the mirror  
 $f$  = focal length of the mirror  
 $m$  = magnification.

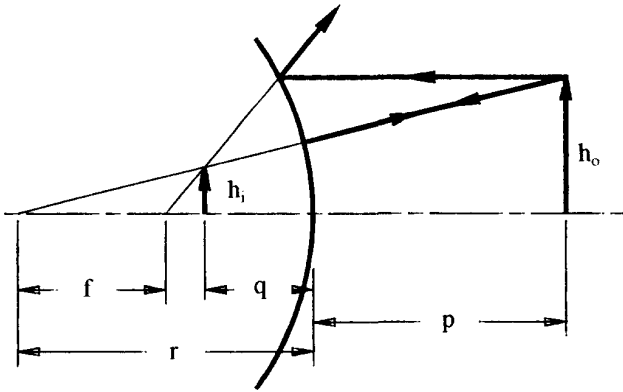


Figure 1

In Figure 1, distances to the right of the mirror are positive and distances to the left are negative. The image distance and the radius will be negative for the convex mirror. The image of the convex mirror is erect and virtual, i.e., an object in the mirror appears standing right side up, and the image cannot be focused on a screen. Concave mirrors have inverted real images which may be focused on a screen.

Since we want to know what an image in the mirror looks like to the driver, let's begin by calculating the image distance and height of an object from EQ(1). The image distance is;

$$q = \frac{rp}{2p - r} \quad \text{EQ(3)}$$

The image height is;

$$h_i = mh_o = \frac{q}{p}h_o, \quad \text{EQ(4)}$$

where  $h_o$  is the height of the object. Substituting EQ(3) into EQ(4), shows that;

$$h_i = \frac{r}{2p - r} h_o. \quad \text{EQ(5)}$$

Note that  $r$  has negative values for the convex mirror and that  $h_i$  does not go to infinity when  $p = r/2$ . The magnification is:

$$m = \frac{h_i}{h_o} = \frac{r}{2p - r}. \quad \text{EQ(6)}$$

The magnification is seen to be a function of the object distance. As a numerical example, choose  $r = -0.5$  ft. and  $p = 5.0$  ft. Then  $m = -0.5$ . How does this compare to a plane mirror? For a plane mirror  $r = \infty$ , and  $m$  is always -1.

Now we know that the convex mirror produces a virtual image smaller than that of a plane mirror and that the image size is a function of the object distance from the mirror. The eye forms an image on its retina of the mirror's virtual image. We could calculate the overall magnification from the object height to the retinal image height if we assumed a "standard" eye with an associated "standard" focal length lens and lens to retina distance. However, as drivers or mirror engineers, we really only want to know how the eye sees the convex mirror image compared to a plane mirror image, i.e., how much smaller is the image from a convex mirror than the image from a plane mirror. To do this, we only need to compare the angles subtended from the eye to the mirror virtual images. This is because the retinal image height is proportional to the subtended angle.

Figure 2 shows the subtended angle,  $\phi$ , for a convex mirror. For simplicity, the eye and the object being viewed are on the axis of the mirror. The eye is shown at a distance  $s$  from the mirror. The construction lines show the image of the object and the angle subtended at the eye by the image.

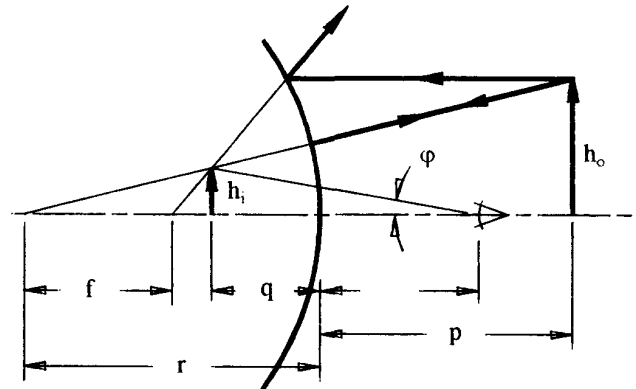


Figure 2

From Figure 2 it is seen that the subtended angle  $\phi$  is;

$$\phi = \tan^{-1} \frac{h_i}{s - q} = \tan^{-1} \frac{rh_o}{(s - q)(2p - r)}$$

$$\phi = \tan^{-1} \frac{h_o}{\frac{2sp}{r} - (s + p)}. \quad \text{EQ(7)}$$

EQ(7) is the subtended angle for a convex mirror, and letting  $r$  go to infinity in EQ(7) gives the subtended angle for a corresponding plane mirror. The relative magnification of the convex mirror compared to the plane mirror will be denoted by  $m_R$ , and it is:

$$m_R = \frac{\tan^{-1} \frac{h_o}{2sp - (s+p)}}{\tan^{-1} \frac{h_o}{-(s+p)}} \quad \text{EQ(8)}$$

While precise, EQ(8) is difficult to interpret at a glance. This can be helped by recalling that ;

$$\tan^{-1} \chi = \chi - \frac{\chi^3}{3} + \frac{\chi^5}{5} - \dots \quad \text{EQ(9)}$$

For an automotive mirror,  $r \cong -5$  ft,  $s \cong 4$  ft, and  $h_o$  is at most  $1/3$  of  $p$ . In this case, the higher order terms are extremely small and they may be ignored. Then;

$$m_R \cong \frac{1}{1 - \frac{2sp}{r(s+p)}} \quad \text{EQ(10)}$$

Finally, we have a simple understandable equation that compares what we would see in a convex mirror with what we would see in a like plane mirror.

Figure 3 is a graph of  $m_R$  vs  $p$  for  $r = -5$  ft and  $s = 4$  ft. It is seen that  $m_R$  goes to unity at  $p = 0$  and to .38 at  $p = \infty$ . As a car approaches, it appears to increase in size at a faster rate than would a car in a plane mirror.

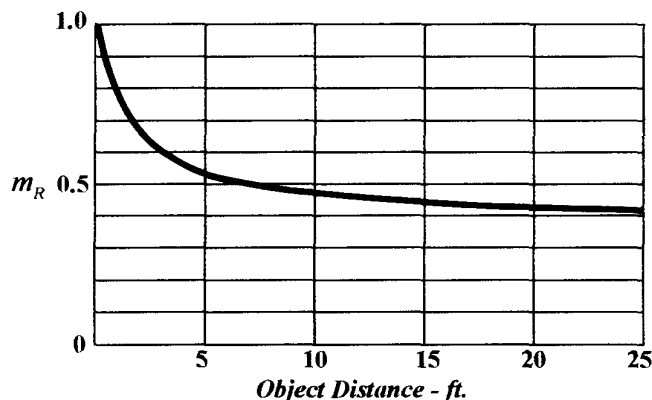


Figure 3

Next, an expression for the viewing angle of a convex mirror will be derived. Figure 4 shows a convex mirror of radius,  $r$ , and width,  $w$ , in a horizontal plane to depict the horizontal viewing angle. An observer is shown at a distance  $s$  from the mirror. The incoming ray shown defines the widest angle that can be seen for the mirror width and eye position depicted. The total viewing angle of the mirror will

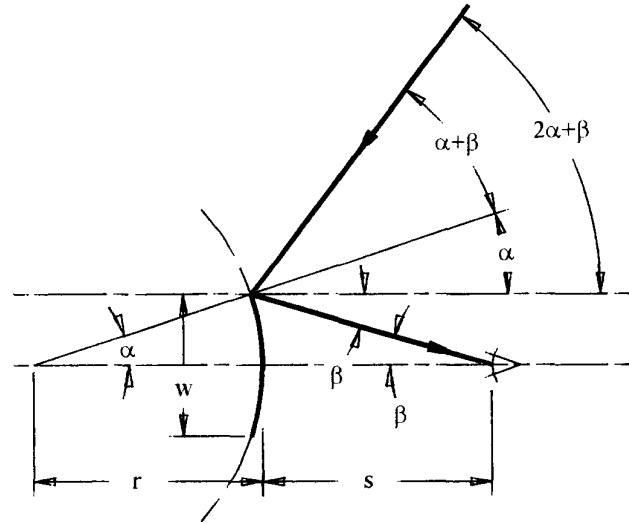


Figure 4

be twice the angle that the incoming ray makes with the axis line. This angle is obviously:

$$\theta = 2(2\alpha + \beta) \quad \text{EQ(11)}$$

Noting that,

$$\alpha = \tan^{-1} \frac{w}{2r} \quad \text{EQ(12)}$$

and,

$$\beta = \tan^{-1} \frac{w}{2s} \quad \text{EQ(13)}$$

then,

$$\theta = 2 \left[ \tan^{-1} \frac{w}{2r} + \tan^{-1} \frac{w}{2s} \right] \quad \text{EQ(14)}$$

It is of interest to compare this angle with the viewing angle of a plane mirror of the same width at the same position. The ratio of the convex mirror viewing angle to the plane mirror viewing angle will be denoted by  $m_R$ , and it is;



One other characteristic of the convex mirror is of interest here, and that is the intensity of light reflected from it. Figure 6 shows a point source of light at a distance  $p$  from a convex mirror, forming a virtual image of the source at distance  $q$  behind the mirror. An eye looks at the mirror from a distance  $s$ . Distances  $r$ ,  $p$  and  $q$  are defined as in EQ(1).

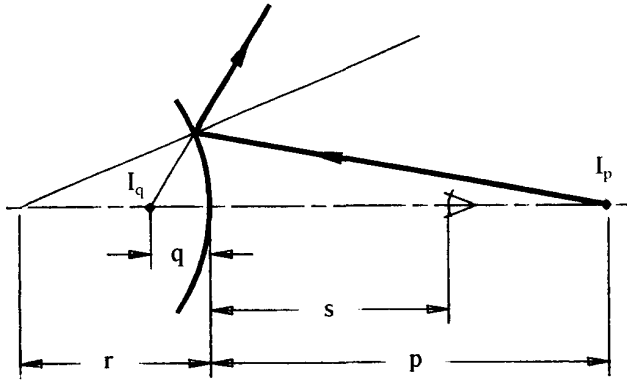


Figure 6

The point source of light has a luminous intensity of  $I_p$ . Then the illuminance at the mirror surface due to  $I_p$  will be;

$$E_1 = \frac{I_p}{p^2}. \quad \text{EQ(22)}$$

The eye sees a point source of light at a distance  $q$  behind the mirror having a luminous intensity of  $I_q$ . If  $I_q$  were a real illuminant, the illuminance at the mirror due to  $I_q$  would be;

$$E_2 = \frac{I_q}{q^2}. \quad \text{EQ(23)}$$

If the reflectance of the mirror is  $\rho$ ,

$$E_2 = \rho E_1, \quad \text{EQ(24)}$$

and,

$$\frac{I_q}{q^2} = \rho \frac{I_p}{p^2}. \quad \text{EQ(25)}$$

Then,

$$I_q = \rho I_p \frac{q^2}{p^2}, \quad \text{EQ(26)}$$

and substituting EQ(3) into EQ(26),

$$I_q = \rho I_p \left( \frac{r}{2p-r} \right)^2. \quad \text{EQ(27)}$$

The illuminance seen by the eye is,

$$E_3 = \frac{I_q}{(s-q)^2}. \quad \text{EQ(28)}$$

If the convex mirror were a plane mirror, the illuminance at the eye due to  $I_p$  would be,

$$E_4 = \frac{\rho I_p}{(s+p)^2}. \quad \text{EQ(29)}$$

The ratio of  $E_3$  to  $E_4$  is the relative illuminance from a convex mirror compared to a plane mirror, and it will be denoted by  $E_R$ .

$$E_R = \frac{I_q}{\rho I_p} \left( \frac{s+p}{s-q} \right)^2, \quad \text{EQ(30)}$$

Substituting EQ(27) into EQ(30),

$$E_R = \left[ \frac{(s+p)r}{(s-q)(2p-r)} \right]^2, \quad \text{EQ(31)}$$

and substituting EQ(3) into EQ(31),

$$E_R = \left[ \frac{(s+p)r}{(s - \frac{pr}{2p-r})(2p-r)} \right]^2,$$

$$E_R = \left[ \frac{1}{1 - \frac{2sp}{r(s+p)}} \right]^2 = n_R^2. \quad \text{EQ(32)}$$

$E_R$  is a measure of the glare potential of a convex mirror. If the mirror has a 55% chromium coating and  $r = -5$  ft,  $s = 4$  ft, and  $p = 100$  ft, the mirror has an effective reflectivity of 8.5%.

Table 1 summarizes the results of EQ(1) through EQ(32), giving a concise statement of the characteristics of both the convex and plane mirror.

| <b><i>Summary of Mirror Characteristics</i></b>       |  |                            |
|---|--|----------------------------|
|   | <b><i>Convex Mirror</i></b>  | <b><i>Plane Mirror</i></b> |
| <b>Relative Magnification</b>                         | $\frac{1}{1 - \frac{2sp}{r(s+p)}} = m_R$                             | 1                          |
| <b>Viewing Angle</b><br>(monocular, on axis)          | $2 \left[ 2 \tan^{-1} \frac{w}{2r} + \tan^{-1} \frac{w}{2s} \right]$ | $2 \tan^{-1} \frac{w}{2s}$ |
| <b>Relative Viewing Angle</b><br>(monocular, on axis) | $m_R \left _{p=\infty} \right $                                      | 1                          |
| <b>Reflected Illuminance</b>                          | $\frac{\rho I_p}{\left[ \frac{2sp}{r} - (s+p) \right]^2}$            | $\frac{\rho I_p}{(s+p)^2}$ |
| <b>Relative Reflected Illuminance</b>                 | $m_R^2$  | 1                          |

Table 1



The equations of Table 1 alone are not enough to define the viewing angles on a car. Most of us see with two eyes, and our eyes are off the axis of the mirror.

Figure 7 shows the viewing angles in a horizontal plane generated by two eyes spaced equidistantly about the axis of

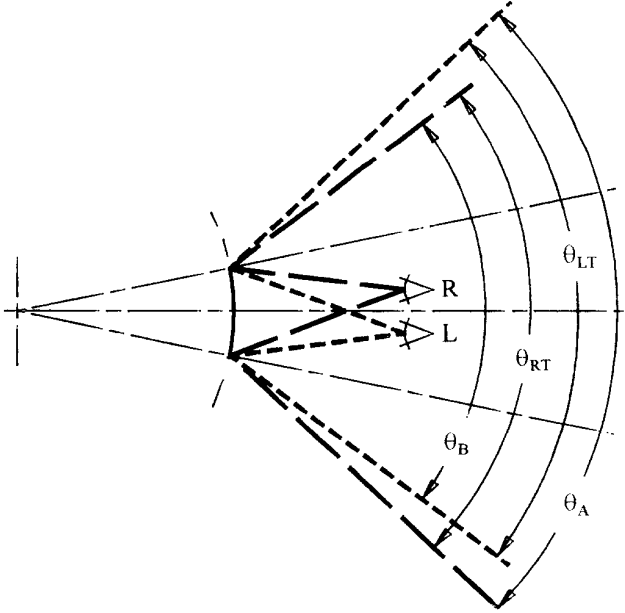


Figure 7

the mirror. The left and right eye viewing angles are designated by  $\theta_{LT}$  and  $\theta_{RT}$  respectively. The total viewing angle generated by both eyes separately is designated  $\theta_A$ . SAE Recommended Practice J1050a calls this total view the ambinocular view. The view where  $\theta_{LT}$  and  $\theta_{RT}$  overlap is marked  $\theta_B$ , and it is designated by J1050a as the binocular view. It will be stereoscopic.

The total viewing angle is easily derived from Figure 8 (half of Figure 7), noting that the widest angle is obtained

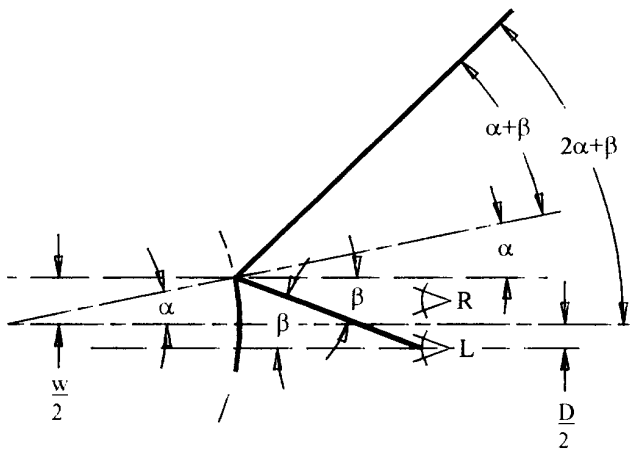


Figure 8

when the left eye looks at the right edge of the mirror and the right eye looks at the left edge of the mirror. We would like to know what angle the incoming ray makes with the mirror axis. If we displace a line parallel to the axis and going through the point where the incoming ray hits the mirror, we can easily calculate the angle which the incoming ray makes with this displaced axis. This angle is equal to the angle the incoming ray makes with the original axis. Twice this angle is obviously the viewing angle of the mirror. In Figure 8.

$$\beta = \tan^{-1} \frac{\frac{w}{2} + \frac{D}{2}}{s} = \tan^{-1} \frac{w + D}{2s}, \quad \text{EQ(33)}$$

and the total viewing angle will be,

$$\theta_A = 2 \left[ 2 \tan^{-1} \frac{w}{2r} + \tan^{-1} \frac{w + D}{2s} \right]. \quad \text{EQ(34)}$$

Again, for off axis viewing,

$$\theta_A \cong 2 \left[ 2 \tan^{-1} \frac{w}{2r} + \tan^{-1} \frac{w \cos \lambda + D}{2s} \right], \quad \text{EQ(35)}$$

where  $\lambda$  is the angle between a line perpendicular to the center of the mirror and a line from the center of the mirror to a point midway between the eyes.

A similar analysis for the binocular viewing angle shows that.

$$\theta_B \cong 2 \left[ 2 \tan^{-1} \frac{w}{2r} + \tan^{-1} \frac{w \cos \lambda - D}{2s} \right]. \quad \text{EQ(36)}$$

This is the same as EQ(35) except for the sign of  $D$ . Table 2 summarizes the viewing angle equations,

| <i>Mirror Viewing Angles</i> |   |   |
|------------------------------|---|---|
|                              | <i>Convex Mirror</i>  | <i>Plane Mirror</i>                         |
| <b>Monocular</b>             | $2 \left[ 2 \tan^{-1} \frac{w}{2r} + \tan^{-1} \frac{w \cos \lambda}{2s} \right]$     | $2 \tan^{-1} \frac{w \cos \lambda}{2s}$     |
| <b>Ambinocular</b>           | $2 \left[ 2 \tan^{-1} \frac{w}{2r} + \tan^{-1} \frac{w \cos \lambda + D}{2s} \right]$ | $2 \tan^{-1} \frac{w \cos \lambda + D}{2s}$ |
| <b>Binocular</b>             | $2 \left[ 2 \tan^{-1} \frac{w}{2r} + \tan^{-1} \frac{w \cos \lambda - D}{2s} \right]$ | $2 \tan^{-1} \frac{w \cos \lambda - D}{2s}$ |

Table 2

| <i>Representative Eye to Mirror Distance - Inches</i> |                                     |       |  |       |  |       |
|---|-------------------------------------|-------|--|-------|--|-------|
| <i>Seat Position</i>                                  | <i>Mirror</i>                       |       |  |       |  |       |
|   | <i>Inside</i><br>w = 8.0 in., r = ∞ |       | <i>Left Outside</i><br>w = 5.75 in., r = ∞ |       | <i>Right Outside</i><br>w = 5.75 in., r = 60 in. |       |
|   | $S_I$                               | $S_t$ | $S_I$                                      | $S_t$ | $S_I$  | $S_t$ |
| <b>Forward</b>  | 9                                   | 14    | 16   | 18    | 16   | 48    |
| <b>Center</b>   | 13                                  | 14    | 20   | 18    | 20   | 48    |
| <b>Back</b>   | 17                                  | 14    | 24   | 18    | 24   | 48    |

Table 3

| <i>Ambinocular Viewing Angle - Degrees</i> |                     |                           |                            |
|--|---------------------|---------------------------|----------------------------|
| <i>Seat Position</i>                       | <i>Inside Error</i> | <i>Left Outside Error</i> | <i>Right Outside Error</i> |
| <b>Forward</b>                             | 31.9                | 18.3                      | 19.1                       |
| <b>Center</b>                              | 28.9                | 16.6                      | 19.0                       |
| <b>Back</b>                                | 25.7                | 15.1                      | 18.9                       |

Table 4

## WHY BLIND ZONES EXIST

Using the equations of Table 2, the viewing angles of automotive rearview mirrors are easily calculated, and with the angles so determined we can make scale drawings to accurately show the blind zones. First, we must select values of the independent variables in the Table 2 equations which will provide the viewing angles of most interest. This was done by taking a mid-size passenger car and measuring the mirror widths, the radius of curvature of the convex mirror, and the eye to mirror longitudinal and transverse distances. The measurements were made for three conditions; driver's seat full forward, centered, and full back. This particular vehicle had a manual seat and the measurements were made with the recliner full forward. Table 3 shows the measurements taken, with distances rounded to the nearest inch.

Table 4 shows the viewing angles obtained by using the measurements of Table 3. Note that short drivers have a considerably better rearview than tall drivers. The viewing angles of the Table 4 center position will be used to depict the viewing angles attained by an average height driver. These viewing angles are shown in Figure 9, which is a scale drawing of a mid-size passenger car in a standard 12 ft. wide

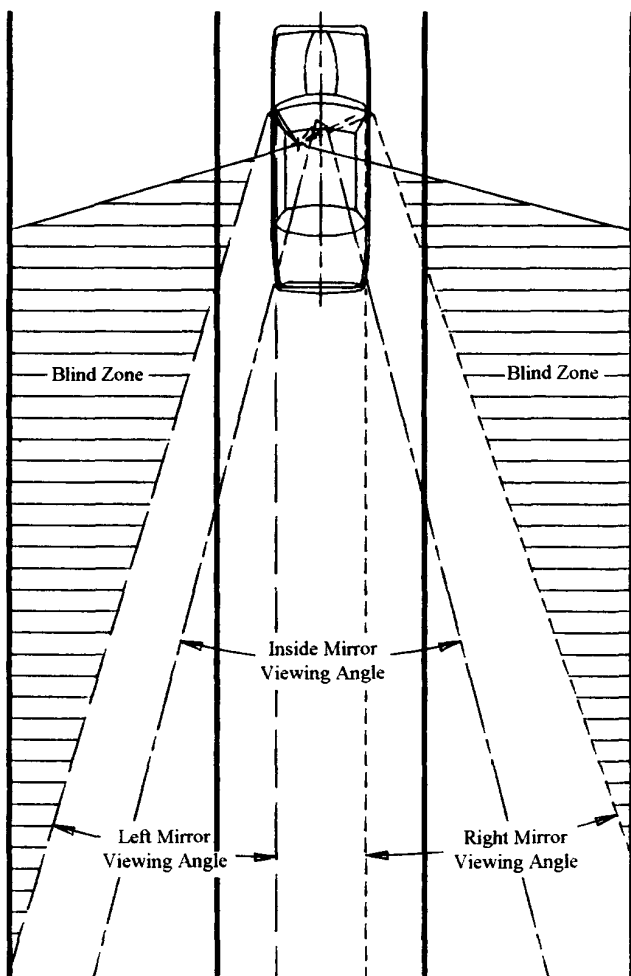


Figure 9

lane. The outside mirrors are adjusted to just see the side of the car. The shaded regions are blind zones which are bounded by the outer vision limits of the outside mirrors and the lines where the driver's peripheral vision begins.

Let's examine the driver's side blind zone more closely, beginning with the peripheral vision line. Figure 10 shows a

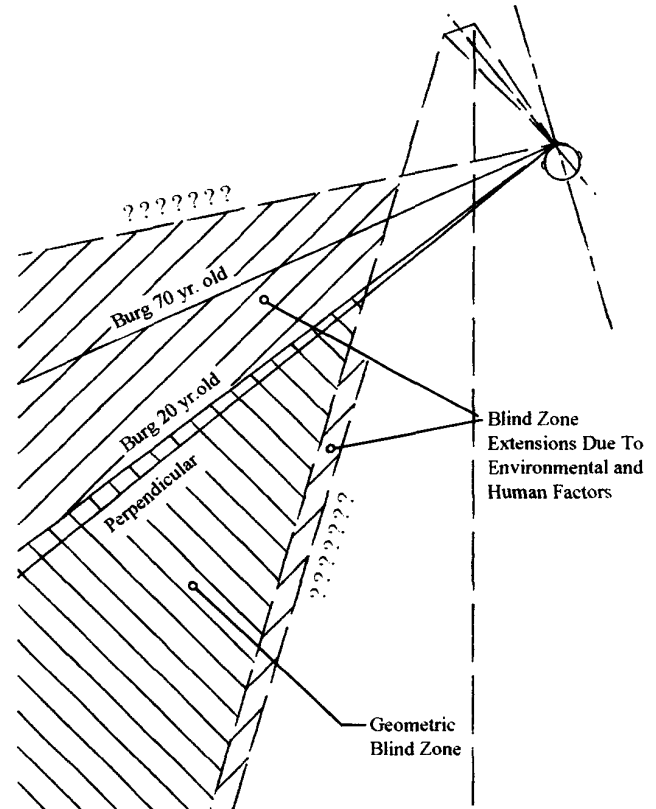


Figure 10

driver with head turned slightly and eyes directed at the outside rearview mirror. If driver's had  $180^\circ$  of forward vision, the peripheral vision line would be perpendicular to a line from the driver's left eye to the mirror. However, as shown by Burg (1968), driver's do not have  $180^\circ$  of vision. The horizontal peripheral vision angle measured from the axis of the eye to the widest angle at which a target is perceived was found by Burg to be a function of age. Burg measured this angle with an apparatus which momentarily introduced a white illuminated object into the subject's field of view. The object was contrasted against a black background, and it would suddenly appear at discrete angular intervals. Thus conditions for detecting the object were good. Burg found that the peripheral vision angle peaked at about  $88^\circ$  at age 20 and diminished to about  $75^\circ$  at age 70.

Ball et al (1988) show that the useful field of view, which involves detection and identification of targets, varies with factors such as the conspicuity of the target, the central task being performed, any distracting influences and age. Significant error rates in target identification were observed at relatively low eccentricities from the fixation point of the eye, as low as  $30^\circ$ .

When the left rearview mirror is used to observe the distance and closing velocity of a following vehicle, the driver's foveal vision is fixed on that mirror. Objects outside the foveal region may or may not be detected for any of the reasons set out by Ball.

Another restriction on the driver's peripheral vision may be the vehicle itself. A tall driver with the seat all the way back, and perhaps partially reclined, may well find that the left B pillar restricts peripheral vision to the left. On the right side, the right seat back, right B pillar and a right side passenger can all restrict the right peripheral vision.

As far as the peripheral vision line is concerned then, it can vary from a couple of degrees less than perpendicular to the *eye to mirror line*, to many degrees less than perpendicular, depending on conditions. Thus, the peripheral vision line is not at a specific location. Only its maximum extent of about  $88^\circ$  is known.

So, we find that the forward edge of the blind zone is variable. How about the rear edge? It might appear that the rear edge of the blind zone is defined by the outer boundary of the viewing angle of the outside mirror and how the mirror is positioned. Geometrically, this is true. If a car is forward of the rear edge of the blind zone, that car will not be seen in the outside mirror. But, if a vehicle is in the blind zone, does it have to be totally forward of the rear edge not to be perceived? Depending on factors such as relative speed, color, contrast and scene content, the probability of perceiving a vehicle only partially within the blind zone can be expected to vary with the amount of the vehicle which is exposed. Data to quantify this has not been found.

One other factor effects the ability to hide a vehicle in the blind zone, and that is the lateral separation of the vehicles. The farther apart the vehicles are laterally, the longer the available space is in which a vehicle can be hidden. Observing cars traveling on multi-lane divided highways, it is observed that vehicles in close proximity tend to separate laterally. Typically, cars separate an additional 2 to 4 feet beyond what the separation would be if they were centered in their lanes.

Summarizing, we can define a geometric blind zone determined by the outer edge of the outside mirror's viewing angle and a line from the driver's eyes which is a couple of degrees less than perpendicular to a line from the eyes to the outside mirror. The actual blind zone is larger than the geometric blind zone because of environmental and human factors and cannot be precisely defined. This is true for both the left and right outside mirrors.

Now let's apply what we know about the blind zones to actual driving conditions. Figure 11 is a scale drawing showing three mid-sized cars on standard 12 ft. wide lanes. The two outer cars are hidden in the center car's blind zones. The hidden vehicles are displaced three feet laterally. The left mirror peripheral vision line is shown at  $85^\circ$  to the *eye to mirror line*, corresponding to a 50 year old driver in Burg's data. The mirror viewing angles are as shown in Figure 9. No other environmental or human factors have been included to reduce the peripheral vision line below  $85^\circ$ . The reality of course, is that it can be far less than the  $85^\circ$  shown, which would result in a larger blind zone.

From Figure 11 three facts are apparent.

1. The blind zones can be large enough to easily conceal a vehicle.
2. The outside mirrors add little additional visibility beyond that provided by the inside mirror. The addition is only a strip about four feet wide.
3. The inside mirror provides by far the best view and the most information. It allows the driver to accurately judge the distance and speed of vehicles approaching from the rear.

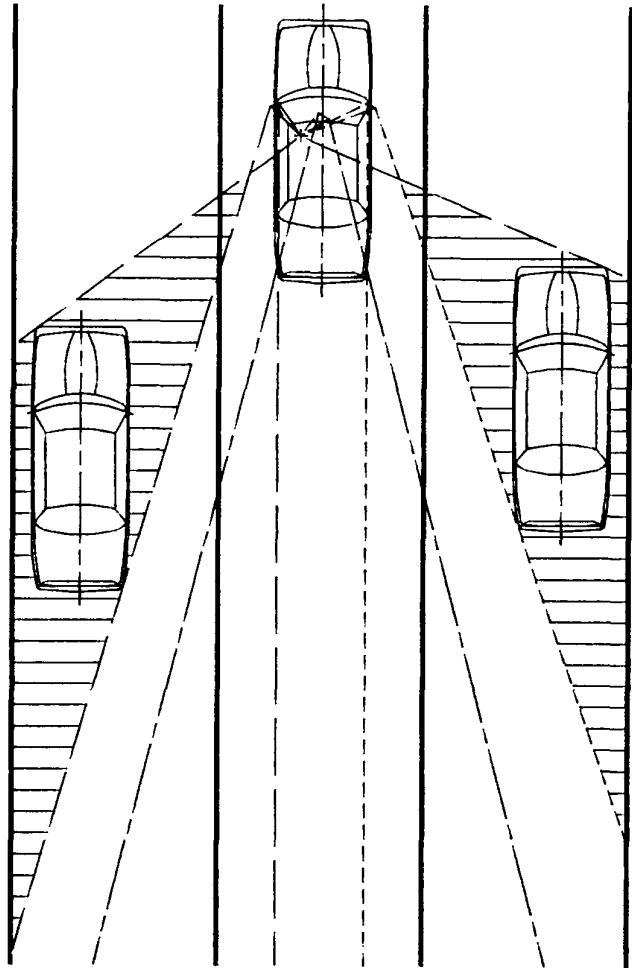


Figure 11

If the inside mirror is so superior, why have outside mirrors? Well, outside mirrors can be useful, especially if the view from the inside mirror is blocked by cargo or by a car immediately to the rear in stopped traffic. The left outside mirror is large enough and close enough to be of value, except it can't be large enough or close enough to eliminate the blind zone without causing other problems. Given that the left mirror is worth putting on a passenger car, despite the blind zone, then we seem to require a right mirror to make the car symmetrical. But putting the same size plane mirror on the right side would produce a nearly useless viewing angle. In fact, the viewing angle for a right side plane mirror

6 inches wide would be only about  $5.5^\circ$ . So instead of a plane mirror, a convex mirror with about a  $20^\circ$  viewing angle is used. The only problem is that the driver can't accurately judge either the distance or approach speed of vehicles seen in it, and it still has a blind zone. However, the stylists are content because the car is symmetrical, and the mirror people appear satisfied because they have more than a  $5.5^\circ$  viewing angle.

## STRATEGIES TO OVERCOME THE BLIND ZONES

Given then that we have inside and outside mirrors, how do we overcome the blind zones produced by them? The most common procedure on passenger cars is to set the outside mirrors to just see the side of the car. When changing lanes, the driver first looks in the outside mirror to determine the position and approach speed of vehicles to the rear and then turns to look for vehicles in the blind zone. There are problems that exist with this procedure. First, the driver must remember to turn and look before changing lanes. Failing to do so can prove disastrous. Second, turning to look into the blind zone results in a loss of forward vision for times in the order of a second. At highway speeds this translates into about 100 feet of travel with the driver's eyes off the road. Third, turning one's head can get tiresome. Fourth, some drivers, especially older ones, have difficulty turning their heads.

One alternative to turning to look into the blind zones would be to increase the horizontal viewing angles of the outside mirrors to about  $35^\circ$ . At such an angle, it is impossible to hide a car in the remaining blind zone. On the right side, a plane mirror with a  $35^\circ$  viewing angle would be 36 inches wide, so that's out. A right side convex mirror 6.5 inches wide would require a radius of curvature of 28 inches, and that is less than the 35 inch minimum required by FMVSS 111. So, we can't get  $35^\circ$  with a reasonably sized right side mirror.

On the left side, a plane mirror with a  $35^\circ$  viewing angle would be 16 inches wide, also unacceptable. A left side convex mirror 6.5 inches wide would require a radius of curvature of 44 inches, but any convex mirror on the driver's side is prohibited by FMVSS 111.

Volvo has developed an interesting solution to the blind zone problem which was first sold in Sweden in 1979 (Pihall, 1981). They use a mirror 6.7 inches wide with a radius of curvature of 82.7 inches on the inner 2/3's of the mirror and then a decreasing radius in the outer 1/3, going down to about a 10 inch radius. The magnification of the inner 2/3's is about 0.7 and the viewing angle is about  $20^\circ$ . The remaining 1/3 captures any vehicle in the blind zone.

Another approach car owners can use to address the blind zone problem is to add *stick on* high curvature mirrors to their existing mirrors, since owners are not restricted by FMVSS 111. *Stick ons* have the disadvantages of reducing the viewing angle of a plane mirror by effectively reducing its width, and of marring the styling of the mirrors. However, a large number of people are sufficiently dissatisfied with their mirrors to resort to *stick ons*. Olson and Winkler (1985)

found in a study of 620 vehicles that 6.6% had *stick on* mirrors on the driver's side mirror.

A simple and logical strategy to overcome the blind zones is suggested by further contemplation of Figure 11. As previously stated, the inside mirror provides by far the best view to the rear. Again, as seen in Figure 11, the outside mirrors actually provide very little additional viewing capability. This being the case, the blind zones can be effectively eliminated simply by rotating the outside mirrors to look into the Figure 11 blind zones as shown in Figure 12. The visible area now increases dramatically, and the remaining blind zones are incapable of hiding a car.

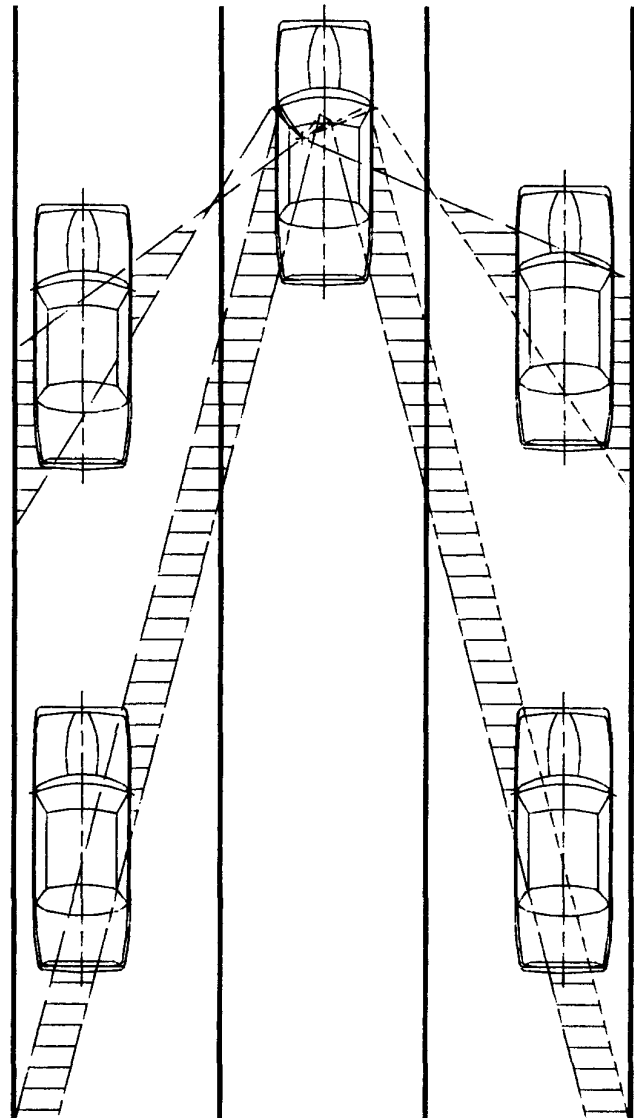


Figure 12

Driving with the mirrors positioned as in Figure 12 calls for a different lane change strategy. With this setting, the driver first looks in the inside mirror to check the position and approach speed of vehicles to the rear. Then, the driver glances at the outside mirror to see if a car is in what used to be the blind zone.

There are many advantages to the Figure 12 setting.

1. It is no longer necessary to turn to look into the former blind zones since they are now visible in the outside mirrors.

2. The forward driving scene is always within the driver's peripheral vision when glancing at the outside mirrors, as opposed to the loss of this forward vision when turning to look into the blind zones.

3. Less time is required for a glance to the outside mirror as compared to turning to look into the blind zone.

4. Older or physically restricted drivers no longer have the difficulty of turning to look into the blind zones.

5. It is now possible to include the former blind zones in a scan of the driving scene by a quick glance to the outside mirrors. Good drivers continually scan. By being able to include the former blind zones in their scanning, drivers will be less likely to forget the blind zones when contemplating a lane change.

6. Glare from the left outside mirror is effectively eliminated. This is because the only headlamps that can be seen in that mirror will be from a single vehicle close by in the left lane. In that position, the intense portion of the headlamp's beam is displaced far enough sideways of the mirror so that it does not produce blinding glare. Only the lower intensity peripheral portion of the beam is seen.

Acknowledging that Figure 12 presents the most logical way to set the mirrors, how then can a driver properly achieve this setting. The viewing areas should be positioned to balance the shaded areas in Figure 12. This requires moving the mirror outward from the Figure 11 position by about  $7^\circ$  to  $8^\circ$ , which in turn moves the viewing area outward by double that amount. One way to do this with the left mirror is to put the side of your head against the window, and then adjust the mirror so that you just see the side of your car. To make sure that this setting is correct, observe a vehicle passing in the left lane while seated in the normal driving position. Make sure that the passing car appears in the outside mirror before it leaves the inside mirror, and that it appears in your peripheral vision before leaving the outside mirror. This assures you that the blind zone has been eliminated. The same procedure can be used with the right side mirror, except, place your head at the center line of the car and then set the right mirror to just see the car's right side.

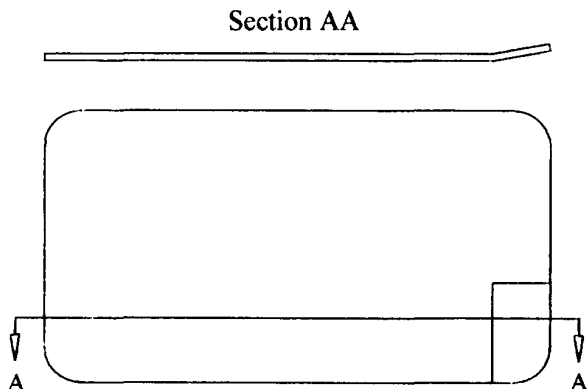
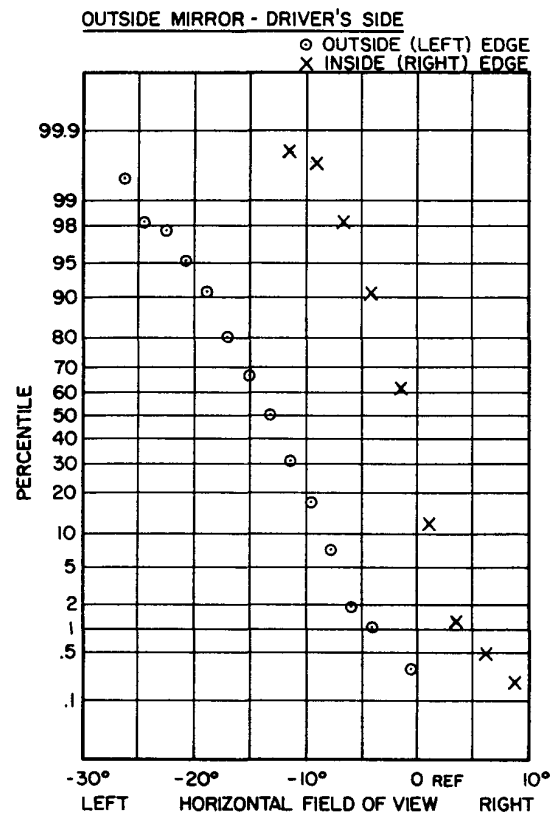


Figure 13

This procedure is cumbersome, and furthermore it is annoying to shift your head back and forth every time you want to see if the setting is correct. A solution to this problem is to have a mirror with a small portion of the lower inner corner canted as shown in Figure 13. The angle of the canted portion relative to the main mirror is  $1/2$  of the angle by which the viewing area is to be moved out away from the Figure 11 position and into the Figure 12 position. The Figure 13 mirror is set by adjusting it so that the side of the car is just seen in the canted portion.

Driving with the mirrors set in the Figure 12 position may require an adjusting period for some drivers. Acclimation to the Figure 12 setting will be easier once the driver fully realizes and accepts that the inside mirror provides all of the rearview information required except for revealing the presence of a vehicle in the former blind zones. The outside mirrors in the Figure 12 setting become simply "go, no-go" devices to tell a driver if there is a car in the former blind zone. Just a quick glance at the outside mirror reveals this.

The Figure 12 setting is already recognized by a small percentage of drivers as being a means of eliminating the blind zones. Olson and Winkler (1985) made measurements on their previously mentioned sample of 620 passenger cars to determine how drivers set their outside mirrors. Figure 14 shows their data for the driver's side outside mirror.



Horizontal field of view measured in the driver's side outside mirrors.

Figure 14



In Figure 14,  $O_{REF}$  is the left side of the car. This data shows that about 50 % of drivers have the left outside mirror set so that the left side of the car is not visible. About 5 % have the mirror turned out so that the inner edge of the field of view is  $5^\circ$  or more away from the side of the car. A fraction of a percent appear to have their mirrors set to the full Figure 12 position. Thus, even in the absence of having the blind zone clearly defined and lacking a precise way to overcome the blind zone, many drivers are naturally leaning in the Figure 12 direction. Olson and Winkler in their conclusions state, *"As typically aimed, there is a great deal of overlap in the fields of view provided by the three mirrors with which most vehicles in the sample were equipped, and coverage to adjacent lanes close to the vehicle is limited. There would seem to be some merit in encouraging drivers to aim their outside mirrors so as to provide better coverage in these important areas."*

We have examined several low technology ways of overcoming the blind zones which could contribute to a reduction in LCM crashes. Chovan et al (1994) have developed high technology IVHS crash avoidance concepts for LCM crashes. These concepts include passive information displays to assist the driver, driver warning systems which provide warning in time for the driver to respond, control intervention systems which partially control the vehicle but do not eliminate driver control, and finally fully automatic control systems which react when the response times required are beyond the driver's capability. All of these systems require sensors which can determine position, velocity and acceleration of the vehicles in the zone of action. Most of the sensors required are available, but implementation revolves around issues of appropriate displays, intervention algorithms and cost. Some high technology counter measures such as detection of vehicles in the blind zones are feasible today. They will be evaluated in terms of cost and effectiveness compared to the lower technology alternatives.

There is one other aspect of overcoming the blind zones worth looking at, and that is the car manufacturer's perspective on this issue. One source of information on their perspective is the vehicle owner's manual. What do we find in these manuals regarding the blind zones? Absolutely nothing. It is as if the blind zones do not exist. Typically, an owner's manual will provide about 100 highlighted and specific warnings on a variety of subjects, but there are no warnings pertaining to the blind zones.

Most manuals instruct the driver to set the outside mirrors so that the side of the car is just visible. Having so instructed the driver, it would appear incumbent on the manufacturer to pictorially show the blind zone generated by this setting. This is not done.

One manufacturer instructs its owners to adjust the outside mirror to be able to see directly behind the car. This implies turning the mirror farther inboard than just seeing the side of the car, and that of course makes the blind zone larger.

Another manufacturer instructs its owners to adjust the *right* side mirror to just see the side of the car, and to adjust the *left* side mirror to center on the adjacent lane with a slight overlap of the view obtained on the inside mirror. This

appears to be a step in the right direction, since it seems that the intent is to reduce the size of the left blind zone, i.e., don't set the left outside mirror to see the side of the car. However, the wording is unclear and more than likely leaves the owner confused.

In view of the information presented here it is apparent that the car manufacturers are not adequately addressing the blind zone problem. The one or two pages of the owner's manual usually devoted to mirrors needs to be expanded to include an explanation and graphical depiction of the blind zones on the car purchased, along with strategies to overcome them.

## CONCLUSIONS AND RECOMMENDATIONS

1. The relative reflected illuminance of a convex mirror is equal to the square of the relative magnification, and the relative viewing angle is equal to the reciprocal of the relative magnification evaluated with the object at infinity.

2. The set of equations shown in Tables 1 and 2 can be used to accurately quantify the pertinent characteristics of automotive rearview mirrors.

3. A vehicle can be easily hidden in the blind zones created by setting the outside rearview mirrors to just see the side of the car.

4. The blind zones can be effectively eliminated if the outside rearview mirror's viewing angles are turned outward away from the side of the car.

5. Glare from the left outside mirror is effectively eliminated when it is turned outward to eliminate the blind zone.

6. An outside rearview mirror with a small canted portion at the lower inside edge can provide a means of properly setting the mirror to view the former blind zones.

7. It is recommended that the car manufacturers use the owner's manual, and any other means available, to explain to car owners why blind zones exist and to offer strategies for overcoming them.

## REFERENCES

- Ball, K.K., Beard, B.L., Roenker, D.L., Miller, R.L., and Griggs, D.S., "Age and Visual Search: Expanding the Useful Field of View," J. Opt. Soc. Am. / Vol.5 / No.12 / p.2210-2219 / Dec.1988
- Burg, A., "Lateral Visual Field as Related to Age and Sex". Journal of Applied Psychology / Vol. 52 / No.1 / p. 10-15 / 1968
- Chovan, J.D., Tijerina, L., Alexander, G., and Hendricks, D.L., "Examination of Lane Change Crashes and Potential IVHS Countermeasures", DOT- VNTSC-NHTSA-93-2 / 1994

## REFERENCES (CONTINUED)

Flannagan, M.J. and Sivak, M., "Indirect Vision Systems", Automotive Ergonomics, Taylor and Francis, London-Washington, D.C., p.205-217 / 1994

Knipling, R.R., "IVHS Technologies Applied to Collision Avoidance: Perspective on Six Target Crash Types", Technical Paper, IVHS America Annual Meeting / 1993

Morrow, I.R.V. and Salik, G., "Vision in Rearview Mirrors", The Optician, Part 2, 144(3732), p.340-345 / 1962

Najm, W.G., Koziol Jr., J.S., Tijerana, L., Pierowicz, J.A., and Hendricks, D.L., "Comparative Assessment of Crash Causal Factors and IVHS Countermeasures", IVHS America Annual Meeting / 1994

Olson, P.L. and Winkler, C.B., "Measurement of Crash Avoidance Characteristics of Vehicles in Use", DOT HS 806 918 / 1985

Pilhall, S., "Improved Rearward View", SAE Technical Paper 810759 / 1981

Platzer Jr., G.E., US Patent No. 5,050,977

Rowland, G.E., Silver, C.A., Volinsky, S.C., Behrman, J.S., Nickols, N.F., and Clisham, W.F., "A Comparison of Plane and Convex Rearview Mirrors for Passenger Automobiles", DOT FH-1 1-7382 / 1970

Walraven, P.L., and Michon, J.A., "The Influence of Some Side Mirror Parameters on Decisions of Drivers", SAE Technical Paper 690207 / 1969

Wang, J., and Knipling, R.R., "Lane Change / Merge Crashes: Problem Size Assessment and Statistical Description", NHTSA Technical Report / DOT HS 808075 / 1994

Vehicle Owner's Manual Collection, Detroit Main Library, National Automotive History Collection

## ABOUT THE AUTHOR

Automotive rearview mirrors have long been of interest to me, and I am a sole or co-inventor in 9 mirror patents.

I have a BSEE and an MS in Physics from Wayne State University and a Master of Automotive Engineering degree from the Chrysler Institute of Engineering.

I am an engineering consultant working in the areas of research and development in electronics and electro-mechanical devices.

Comments or questions on this paper may be addressed to me at 424 Cypress Road, Rochester Hills, MI 48309