Effects of Misaimed Low Beams and High Beams on Visual Detection of Reflectorized Targets at Night

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An analytical study was conducted on a microcomputer to assess the effects of misaimed low beams and high beams on the visual detection of reflectorized targets of different brightness, such as reflectorized warning signs, overhead guide signs, license plates, and post delineators. The study was done at night, on a straight and a left-curved section of highway. The model used computed all the geometric distances and angles necessary for a selected driver-vehicle-reflectorized target situation for each headlamp, the amount of beam illumination that is returned to a driver's eyes for selected environmental and vehicle conditions, and a Multiples of Threshold value. Calculations were performed for a matrix containing 25 passenger-side and driver-side beam misaim combinations (5 × 5 points, identical and nonidentical misaims). The results show that both vertical and horizontal beam misaim may have a detrimental effect upon the detection distance of reflectorized targets in the driving environment: however, the use of brighter retroreflective materials can help to offset the detrimental distance effect in most cases.

This study shows the effect of beam misaim on a driver's ability to detect reflectorized (the use of retroreflective materials) targets of different brightness at night ahead of the vehicle, in the absence of glare from opposing traffic. This paper does not address the glare effects misaimed beams might have on opposing traffic or the effect glare from opposing traffic might have on a driver's detection performance. Detection of reflectorized targets is emphasized since it is the first step in a driver's hazard avoidance process as modeled by McGee et al. (*1*). McGee's model consists of a five-step sequential process during which the driver detects an object causing a hazardous condition, recognizes the condition, decides upon a response, responds to the condition, and successfully maneuvers the vehicle to avoid the hazard. Although this model was suggested for the avoidance of an object on the highway, it might be adapted to describe a driver's response to reflectorized targets, such as traffic signs, at night. It is imperative that the targets be detectable at a sufficient distance to allow a driver to effectively execute the maneuver in a safe manner within the available time period.

Bhise et al. (*2*) investigated the effect of a H4656 low beam misaim on a driver's visual performance using the Comprehensive Headlamp Environment Systems Simulation (CHESS) model, developed at Ford Motor Company. The CHESS model considers the pedestrians detected, delineation visibility, discomfort glare to oncoming drivers, and glare effects by opposing traffic. The model represents its final result as a Figure-of-Merit, which is "the percentage of the total distance traveled by the simulated drivers over the standardized test route for which the headlighting satisfies a certain preselected vision performance level criterion." Also investigated were random beam misaim and combinations of seven horizontal and five vertical identical passenger and driver side beam misaim conditions. The random beam misaim condition was based on low beam misaim data from a 1971 study (*3*). It was assumed that the beam misaims followed a bivariate normal distribution with an average misaim of .08° to the right and .73° below the correct aim position, and with a horizontal standard deviation of .86° and a vertical standard deviation of 1.55°. It was also assumed that the horizontal misaim was independent and the vertical misaim was identical for both low beams. The random beam misaim simulation included about 99.9 percent of the vehicle population (tolerance limits of three standard deviations in both directions). The results showed that the performance of the randomly misaimed low beams produced a significantly lower Figure-of-Merit at the 90 percent confidence level than correctly aimed low beams. For the second condition, both headlamps were aimed at one of seven horizontal levels and one of five vertical aim levels, while all opposing vehicle's headlamps were always correctly aimed. The results showed that the low beam system Figure-of-Merit could be significantly reduced by vertical headlamp misaims of 4 in and 8 in below the correct aim at 25 ft. The performance of the H4656 low beam is less sensitive to horizontal misaims between 4 in left and 12 in right than to vertical misaims between 4 in up and 8 in down at 25 ft.

A more recent survey (*4, 5*) of the aim of a vehicle's low beams indicates that the vertical misaim variability of low beams has a standard deviation of .9°, which is much smaller than the 1.55° used by Bhise et al. The horizontal beam misaim standard deviations are about .8°, which is close to the standard deviation of .85° used by Bhise et al. The effect of horizontal and vertical beam misaim upon a driver's ability to detect reflectorized targets of different brightness at night in the driving environment should be investigated. In addition, the recent vertical misaim variability survey is considerably smaller than Hull et al.'s (*3*) vertical misaim variability, and the CHESS model does not consider detection or recognition of reflectorized targets, such as traffic signs. Further, no study was found that has systematically investigated the effect of nonidentical vertically misaimed headlamps. Since both headlamps contribute to the total reflected illumination which is returned to a driver's eyes, the effect of nonidentical and identical misaimed headlamps and close-to-correct aimed

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headlamps (low beams and high beams) on detection distance for reflective materials of different brightness needs to be investigated.

APPROACH

An interactive computer program, developed for a Macintosh microcomputer, analytically determined the detection distance of reflectorized targets in the driving environment. This program calculated the illuminance (E_{ref}) in footcandles (fc) produced at a reflective target, based upon

$$E_{ref} = I * t^{(a/100)}/a^2 \tag{1}$$

where I is the luminous intensity of the light source (in this case, either the left or right headlamp) in candela (cd), t is the transmissivity of the atmosphere per unit distance (100 ft), and a is the direct distance from the light source to the reflector in feet. Knowing the specific intensity (SI) of the reflector at given entrance, observation, presentation, and rotation angles, the same basic relationship can be used to determine the illumination which is returned to a driver's eyes (E_{eyes}) in fc. This relationship may be expressed as

$$E_{eyes} = E_{ref} * SI * C * t^{(b/100)}/b^2 \tag{2}$$

where SI is the specific intensity of the reflector in cd/fc/ft^2, C is the area of the reflector in ft^2, and b is the direct distance from the reflector to the driver's eyes. Combining these relationships into one, the illumination directed to the driver's eyes from either the right or left headlamp can be calculated from

$$E_{eyes} = I * SI * C * t^{(a+b)/100}/(a^2 * b^2) \tag{3}$$

The user inputs the vehicle and driver geometry, highway geometry, and the geometry of the reflector into the computer program. The program then calculates the geometric angles and euclidean distances at user specified rectilinear distances. The user inputs the headlamp aim, beam, and reflector efficiency factors, windshield transmission factor, environmental conditions and selects the headlamp and reflector data files. The program calculates the illumination levels at the driver's eyes due to the right, left, and both headlamps. It then selects the threshold luminance value for a 98 percent probability of detection of a white point source, based upon a user-selected background luminance value from the IES Handbook (*6*,p.3–24). This illumination threshold applies only to point sources, but the program automatically adjusts for sources that are too large to be considered point sources based upon values from the IES Handbook (*6*,p.3–25). To provide a framework where the small illumination values in footcandles (fc) at a driver's eyes can be compared on a one-to-one basis with visual backgrounds having different luminance levels, and to obtain numbers tied more closely to human detection performance, the final illumination values and adjusted threshold value are used to calculate a Multiples of Threshold (MOT) value. The MOT is defined as the number of times the illumination level, which is returned to a driver's eyes from the reflector, is above the illumination threshold for a 98 percent probability of detection of a white point source against a uniform background in the laboratory. The program then displays the reflector and beam angles, beam candlepower values, illumination at the reflector and driver's eyes due to the left, right, and both beams and the MOT values for a selected set of distances ahead of the vehicle.

A MOT value must be selected as a criterion value that will be representative for the detection of reflectorized targets in the driving environment. Most published detection threshold values were obtained in the laboratory, against uniform backgrounds, with subjects who were alerted, highly motivated, and had a low information processing work load. Such laboratory threshold values would be unsatisfactory for the detection of targets in the driving environment where the background may contain numerous light sources, the driver is unaware of an upcoming target, and the information work load may be relatively high. For this reason, Zwahlen (*7*) has recommended the use of a MOT value as high as 1,000 (which is between a human brilliancy rating of "satisfactory" and "bright" according to Breckenridge and Douglas (*8*)) for the timely detection of an unexpected reflectorized target (point source) such as a reflectorized pedestrian or bicycle rider at night. A MOT value of 60 (17.1×10^{-8} fc or 1.84 km candles) was selected as a criterion value that corresponds to a human brilliancy rating between faint (.9 km candles) and weak (4 km candles) according to Breckenridge and Douglas. The same MOT value of 60 was used for the fourth post delineator ahead of the car in an earlier study by Zwahlen et al. (*9*) when optimizing the spacing of post delineators.

ASSUMPTIONS AND ANALYSIS COMBINATIONS

Assumptions include vehicle-driver dimensions for a 50 percent person in a typical large car, when the car is driven in the center of a 12 ft wide right-hand lane, a background luminance of .01 fl., atmospheric transmissivity of .99/100 ft (clear), a windshield transmittance of .9 and a beam efficiency of 90 percent. The halogen 6054 high beams and low beams were investigated in this study.

Selected reflectorized targets included a warning sign located either on the right or left side of the highway, an overhead guide sign, a post-mounted reflective sheeting patch (flexible post delineator) on the right side of the highway, and a reflectorized license plate located on either the left or right side of the highway. According to sections 2E-2 and 2E-4 of the Ohio Manual of Uniform Traffic Control Devices (*10*), warning signs should be placed a minimum of 12 ft from the edge of the highway and the bottom of the sign should be at least 5 ft above the near edge of the pavement on rural roads and at least 6 ft above the near edge of the pavement on expressways and freeways. Therefore, it was assumed the yellow warning sign was 30 in × 30 in, the corner of the sign nearest the highway was 12 ft from the edge line of the highway, and the bottom of the sign was 6 ft above the nearest edge of the highway. Section 2E-4 of the Ohio Manual of Uniform Traffic Control Devices states that overhead guide signs should provide a vertical clearance of not less than 17 ft unless a lesser clearance is used for the design of other structures. Hence, it was presumed that the overhead sign was 12 ft wide, 9 ft tall, and centered in the driver's lane with a vertical clearance of 17 ft. Section 4B-3 and 4B-5 of the manual specifies that the top of the reflecting patch (6 × 3 in) of the post delineator should be placed 4 ft, plus or minus one in, above the near roadway edge. It also states that all delineators should be between 2 ft and 12 ft 6 in from the edge of the pavement and the reflective patch should have a minimum dimension of 3 in. The center of the reflective patch was assumed to be 12 ft to the right and 48 in above the right edge of the pavement, which is 3 in higher than the vertical center of a correctly installed reflective patch. The patch was assumed to have the rectangular dimensions of 3 in wide by 6 in tall. A small random survey of 20 late model vehicles indicated that the center of the rear license plate was located an average of 2.1 ft above the ground. Therefore, it was assumed that the license plate in this study was located at this height above either the right edge or left edge line. It was also assumed that the license plate had a reflectivity of 23 CIL and was 6 in tall and 12 in wide.

It was further assumed that the white/silver reflective material used on post delineators and license plates operated with a 90 percent efficiency due to wear and tear and dirt accumulation. It was assumed that the specific intensity of the yellow reflective material is 60 percent of the specific intensity of the white material (values between 59.6 and 62.5 percent (*11*)) and 90 percent efficient (overall reflectivity was 54 percent). The specific intensity of the green reflective material was assumed to be 15 percent of the specific intensity of the white material and 90 percent efficient (overall reflectivity was 13.5 percent).

Olson and Winkler (*4*) and Olson (*5*) have described a survey of the condition of certain key vehicle safety systems, including lighting equipment, of a sample of 964 vehicles. These reports give horizontal and vertical averages and standard deviations for the misaim of low beams. Since the data collected was obtained at gas stations after the drivers completed refueling, the reports recommend that the standard deviation for the vertical aim be increased from 0.9° to 1.0° as an allowance for this bias. Mechanical aimers were used to measure the misaim of the beams up to 10 in at 25 ft (plus or minus 1.9°) in both directions. The original low beam misaim data (*4*) (on a computer tape) was obtained from the NHTSA in Washington, D.C., and further analysis provided the additional results on low beam misaim which are included in the following section.

Figures 1 through 4 show frequency distributions and statistical calculations of the measured misaim for the horizontal and vertical directions of the driver and passenger side low beams. Figures 1 and 3 show that low beam misaims can be assumed to be normally distributed in the vertical direction for both low beams (based upon a Chi-Square test conducted at the .01 level). However, Figures 2 and 4 indicate that the horizontal misaims for both low beams are not normally distributed (based upon a Chi-Square test at the .01 level). Low-beam misaims of plus or minus 10 in. in both directions at 25 ft were measured a total of 126 times for the driver's side low beam and 123 times for the passenger side low beam (see Figures 1 through 4). Thirteen of the driver's side and 16 of the passenger's side low beams were misaimed by more than 10 in at 25 ft in both the horizontal and vertical directions. These results indicate that the mechanical aimers were unable to measure the exact beam misaim for 13 percent of the low beams.

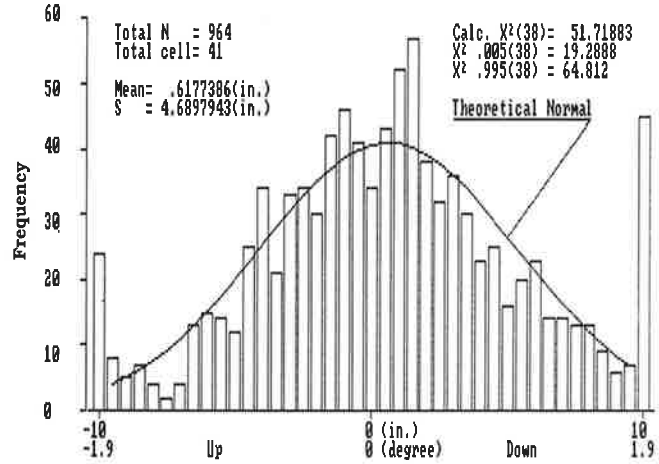

FIGURE 1 Histogram and statistical calculations of the measured vertical low beam misaims for the driver's side headlamp.

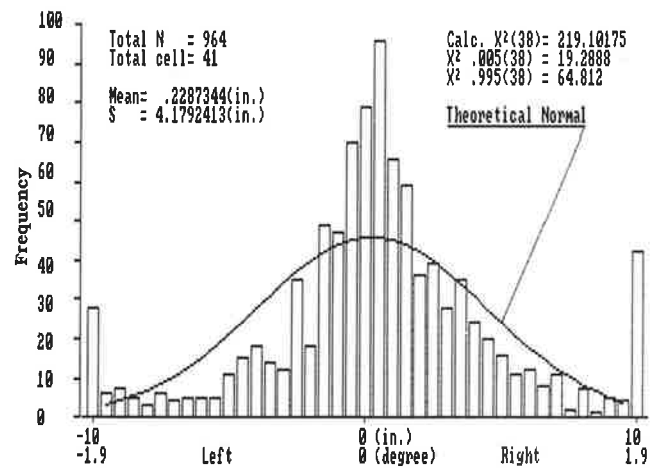

FIGURE 2 Histogram and statistical calculations of the measured horizontal low beam misaims for the driver's side headlamp.

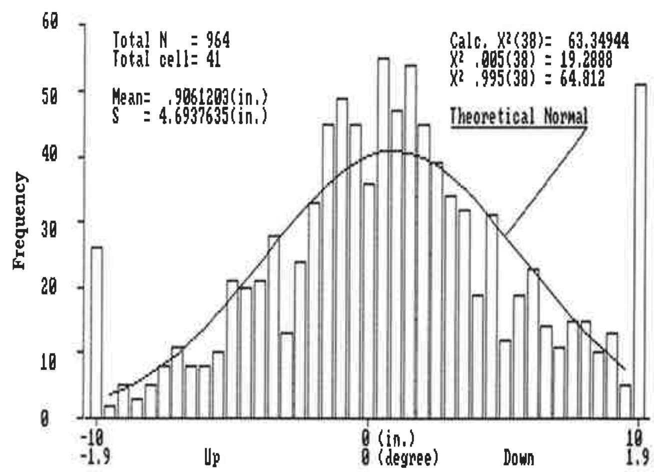

FIGURE 3 Histogram and statistical calculations of the measured vertical low beam misaims for the passenger's side headlamp.

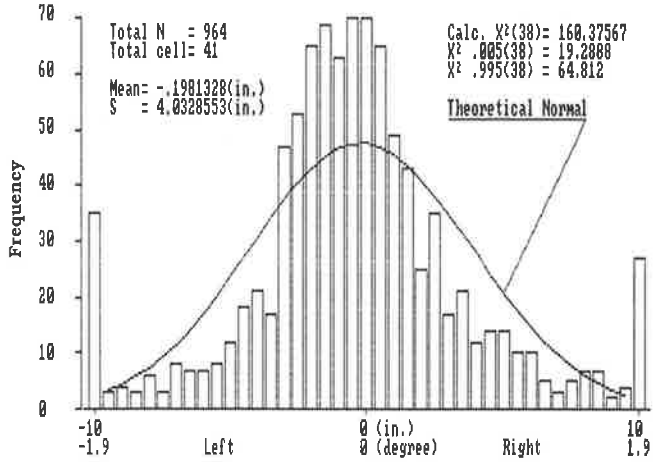

FIGURE 4 Histogram and statistical calculations of the measured horizontal low beam misaims for the passenger's side headlamp.

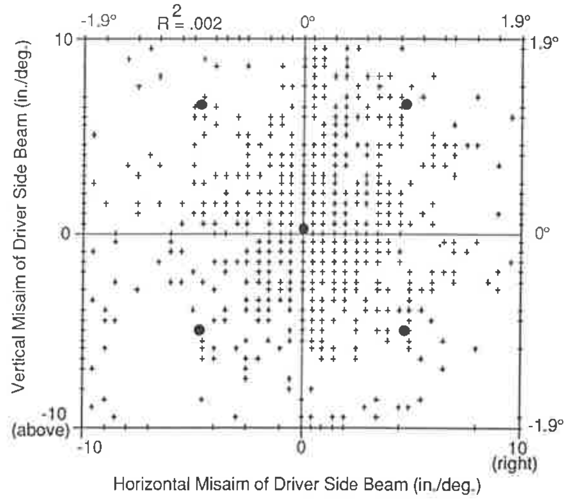

FIGURE 5 Selected low beam misaim positions overlaid on the beam misaim plot for the driver's side headlamp.

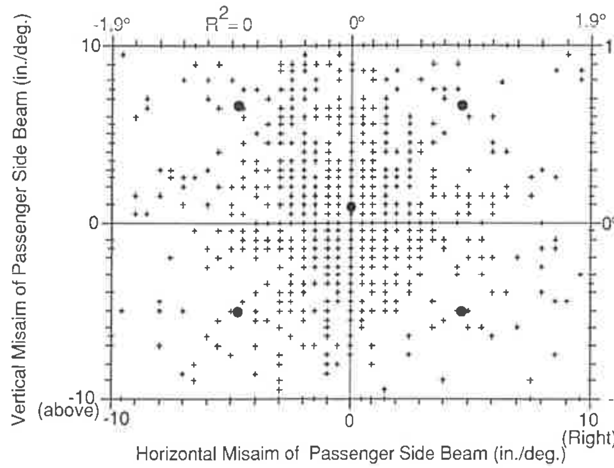

FIGURE 6 Selected low beam misaim positions overlaid on the beam misaim plot for the passenger's side headlamp.

The low beam misaim data was also used to determine if any relationships exist between the two low beams or between the horizontal and vertical directions of either beam. A small correlation coefficient (R) of 0.18 (R^2 = .031) was found for the horizontal misaims of the driver and passenger side low beams, and a small to moderate correlation coefficient of 0.63 (R^2 = .392) was found for the vertical misaim. There is practically no correlation between the vertical and horizontal misaim of the driver's side low beam (R = 0.04, R^2 = .002) or between the vertical and horizontal misaim of the passenger side low beam (R = 0.00, R^2 = 0).

To keep the number of calculations within manageable limits, five beam misaim angles were selected for both the passenger's and driver's side headlamps. These included a beam misaim of .15° below the correct aim position and 0° in the horizontal direction, which is close to the average overall beam misaim given by Olson and Winkler. The remaining four points were obtained by adding and subtracting 1.1° in the vertical direction and .9° in the horizontal direction. These values are close to the standard deviations given by Olson and Winkler, however, small adjustment values were added to account for increased variability possibly present on the highways for cars that had not just refueled and the fairly small increased variability had the mechanical aimers been able to measure beam aims of greater than 10 in at 25 ft. Figures 5 and 6 show the five selected low beam misaim angles overlaid on the beam misaim plot for the driver's side headlamp and the passenger's side headlamp, respectively. If a square were drawn through the four low beam misaim points, it would enclose 63.3 percent of the misaim points for the driver's side low beam and 64.7 percent of the misaim points for the passenger's side low beam. A circle through these four points would enclose 75.3 percent of the misaim points for the driver's side low beam and 75.1 percent for the passenger side.

Based on these assumptions, the computer program was used to determine detection distances for each of the 25 passenger and driver side low beam misaim combinations (5 × 5 points, identical and nonidentical misaims). In addition, the effect of high beams was also determined. Since no data on high beam misaim was available, the percentage of misaim for vehicles with two and four headlamps was found using the same five misaim points. Also determined were three levels of reflectivity (prismatic sheeting material with a specific intensity of 1080 cd/fc/ft² at a −4° entrance angle and a .2° observation angle, encapsulated lens sheeting material with a specific intensity of 309 cd/fc/ft², and enclosed or embedded lens sheeting material with a specific intensity of 105 cd/fc/ft²), and roadway geometry (straight highway or a 2000 ft radius (2.9°) left curve).

RESULTS

Figure 7 shows detection distances and percentages for a warning sign on the right side of a straight section of highway for high and low beam conditions, three retroreflective sheeting materials, and 25 combinations of beam misaim. The percentages were obtained by dividing the detection distance for each beam misaim combination by the detection distance obtained for the nearly correct aim position (both beams correctly aimed in the horizontal direction and 0.15° below the correct aim in the vertical direction). The shaded matrix cells indicate detection distances that are less than the detection distance for the nearly correct aim position. The lightest shaded area indicates detection distances of 90 to 100 percent for the nearly correct aim position and each successively darker shaded area represents a further 10 percent decrement. The low beam detection distances shown in Figure 7 range from 1,243 ft to 4,104 ft. For the right warning sign, if either low beam is aimed .95° above the correct aim position, the detection distance will be greater than the detection distance for the nearly correct aim position. This is due to the nonlinear characteristics of the low beam isocandela distribution and the location of the hottest point of the low beam (about 2° down and 2° to the right). However, it should be noted that under low beam misaim conditions, where they are aimed above or to the left of the correct aim position, the low beams will produce higher levels of disability and discomfort glare to oncoming drivers. Figure 7 also shows that the detection distances for the high beams range from 2,668 feet to 5,039 feet.

Figure 8 shows detection distances and percentages for a warning sign on the left side of a straight section of highway, for high and low beam conditions, three retroreflective materials, and 25 combinations of beam misaim. The low beam detection distances range from 1,068 feet (point source size correction factor of 1.16) to 3,774 feet. These detection distances are somewhat shorter than for the right side of the highway shown in Figure 7, especially for the low beam. Figure 8 also shows that if either low beam is aimed .95° above the correct aim position, the detection distance for the warning sign on the left side of the highway will be greater than the detection distance for the nearly correct aim position. Further, it shows that the detection distances for the high beams range from 2,509 feet to 4,918 feet. In general, the best detection conditions are obtained when one of the high beams is nearly correctly aimed, and the second best detection distances are obtained when the beam aim is .9° left and .95° above the correct aim position.

Driver Side \ Passenger Side		Reflect. Material	● H.9° V.95°		H.9° ● V.95°		H0° V.15°		V1.25° ● H.9°		H.9° V1.25° ●	
			Dist	%	Dist	%	Dist	%	Dist	%	Dist	%
Lowbeam Straight	● H.9° V.95°	Pris.	4104	152	3770	139	3655	135	3605	133	3591	133
		Enc.	3159	154	2893	141	2805	136	2760	134	2748	134
		Encl.	2498	155	2292	142	2213	137	2182	135	2174	135
	H.9° ● V.95°	Pris.	3767	139	3250	120	3031	112	2917	108	2884	107
		Enc.	2889	141	2485	121	2305	112	2223	108	2196	107
		Encl.	2286	142	1955	121	1815	113	1738	108	1721	107
	H0° V.15°	Pris.	3644	135	3017	112	2704	100	2522	93	2460	91
		Enc.	2793	136	2297	112	2056	100	1917	93	1871	91
		Encl.	2201	137	1809	112	1612	100	1506	93	1470	91
	V1.25° ● H.9°	Pris.	3592	133	2895	107	2514	93	2259	84	2170	80
		Enc.	2746	134	2208	107	1905	93	1701	83	1646	80
		Encl.	2170	135	1727	107	1494	93	1336	83	1287	80
	V1.25° H.9° ●	Pris.	3577	132	2864	106	2449	91	2167	80	2072	77
		Enc.	2736	133	2179	106	1856	90	1646	80	1569	76
		Encl.	2162	134	1709	106	1456	90	1287	80	1243	77
Highbeam Straight	● H.9° V.95°	Pris.	4670	93	4646	92	4866	97	4557	90	4530	90
		Enc.	3603	92	3591	92	3762	96	3503	90	3490	89
		Encl.	2865	92	2862	92	2991	96	2772	89	2769	89
	H.9° ● V.95°	Pris.	4654	92	4630	92	4851	96	4540	90	4512	90
		Enc.	3599	92	3588	92	3758	96	3500	90	3488	89
		Encl.	2868	92	2865	92	2993	96	2778	89	2774	89
	H0° V.15°	Pris.	4872	97	4851	96	5039	100	4780	95	4757	94
		Enc.	3768	97	3757	96	3902	100	3685	94	3673	94
		Encl.	2997	96	2993	96	3106	100	2923	94	2919	94
	V1.25° ● H.9°	Pris.	4558	90	4531	90	4773	95	4429	88	4398	87
		Enc.	3504	90	3491	89	3679	94	3387	87	3374	86
		Encl.	2773	89	2770	89	2916	94	2663	86	2661	86
	V1.25° H.9° ●	Pris.	4538	90	4511	90	4756	94	4407	87	4378	87
		Enc.	3498	90	3486	89	3673	94	3383	87	3369	86
		Encl.	2776	89	2774	89	2918	94	2669	86	2668	86

┼ Correct Aim of Headlamp ● Actual Aim of Headlamp

Dist. - Distance (ft.) From the Object to the Driver for an Illuminance of 60 MOT

% - Distance Obtained for Actual Headlamp Misalignment Expressed as a Percentage of the Distance Obtained for the Average Headlamp Position

Pris. - Prismatic Sheeting Material Enc. - Encapsulated Lens Sheeting Material

Encl. - Enclosed or Embedded Sheeting Material

FIGURE 7 Detection distances and percentages for a warning sign on the right side of a straight section of highway for high and low beam conditions, three different retroreflective materials, and 25 passenger's and driver's side beam misaim combinations.

Driver Side \ Passenger Side		Reflect. Material	● H .9° V .95° Dist	%	H .9° ● V .95° Dist	%	H 0° V .15° Dist	%	V 1.25° ● H .9° Dist	%	V 1.25° H .9° ● Dist	%
Lowbeam Straight	● H .9° V .95°	Pris.	3774	160	3397	144	3323	140	3283	139	3263	138
		Enc.	2764	160	2477	144	2411	140	2375	138	2351	136
		Encl.	2014	154	1813	139	1747	134	1728	133	1710	131
	H .9° ● V .95°	Pris.	3361	142	2727	115	2572	109	2485	105	2429	103
		Enc.	2413	140	2019	117	1889	110	1840	107	1791	104
		Encl.	1804	138	1537	118	1436	110	1401	107	1363	105
	H 0° V .15°	Pris.	3274	138	2569	109	2366	100	2253	95	2168	92
		Enc.	2327	135	1885	109	1724	100	1653	96	1582	92
		Encl.	1737	133	1428	110	1304	100	1260	97	1210	93
	V 1.25° ● H .9°	Pris.	3224	136	2469	104	2237	95	2109	89	2001	85
		Enc.	2281	132	1825	106	1646	95	1565	91	1484	86
		Encl.	1714	131	1387	106	1258	96	1195	92	1135	87
	V 1.25° H .9° ●	Pris.	3200	135	2415	102	2147	91	2001	85	1877	79
		Enc.	2252	131	1771	103	1573	91	1477	86	1386	80
		Encl.	1695	130	1342	103	1204	92	1127	86	1068	82
Highbeam Straight	● H .9° V .95°	Pris.	4708	96	4600	94	4813	98	4593	93	4500	92
		Enc.	3642	96	3542	94	3705	98	3540	94	3459	92
		Encl.	2895	97	2804	94	2934	98	2806	94	2732	92
	H .9° ● V .95°	Pris.	4607	94	4491	91	4722	96	4483	91	4374	89
		Enc.	3548	94	3441	91	3623	96	3439	91	3342	88
		Encl.	2812	94	2704	91	2854	96	2708	91	2616	88
	H 0° V .15°	Pris.	4822	98	4725	96	4918	100	4718	96	4631	94
		Enc.	3713	98	3626	96	3780	100	3623	96	3542	94
		Encl.	2942	99	2856	96	2979	100	2857	96	2784	93
	V 1.25° ● H .9°	Pris.	4594	93	4475	91	4710	96	4466	91	4357	89
		Enc.	3540	94	3431	91	3615	96	3428	91	3331	88
		Encl.	2806	94	2699	91	2848	96	2702	91	2611	88
	V 1.25° H .9° ●	Pris.	4506	92	4372	89	4627	94	4364	89	4238	86
		Enc.	3465	92	3339	88	3537	94	3337	88	3221	85
		Encl.	2738	92	2613	88	2779	93	2619	88	2509	84

—|— Correct Aim of Headlamp ● Actual Aim of Headlamp
Dist. - Distance (ft.) From the Object to the Driver for an Illuminance of 60 MOT
% - Distance Obtained for Actual Headlamp Misalignment Expressed as a Percentage of the Distance Obtained for the Average Headlamp Position
Pris. - Prismatic Sheeting Material Enc. - Encapsulated Lens Sheeting Material
Encl. - Enclosed or Embedded Sheeting Material

FIGURE 8 Detection distances and percentages for a warning sign on the left side of a straight section of highway, for high and low beam conditions, three different retroreflective materials, and 25 passenger's and driver's side beam misaim combinations.

Figure 9 shows detection distances and percentages for an overhead guide sign on a straight section of highway for high and low beam conditions, two different retroreflective materials, and 25 combinations of beam misaim. From this figure, it can be seen that the detection distances range from 2,256 (point source size factor of 1.66) to 5,390 ft for the low beams and 4,527 to 6,692 ft for the high beams. These detection distances are surprisingly large, apparently due to the large reflective area (108 ft^2) of the sign. Detection distances longer than the detection distance for the nearly correct low beam position are obtained if either low beam is aimed .95° above the correct aim position. Further, Figure 9 shows that low and high beam detection distances of less than 90 percent of the detection distance for the nearly correct beam position are obtained only when both beams are aimed 1.25° below the correct aim position.

Figure 10 shows detection distances and percentages for the post delineator patch along a straight and a left-curved section of highway, two retroreflective sheeting materials, and 25 combinations of low beam misaim. The low beam detection distances range from 701 ft to 1,992 ft on the straight section of highway and from 472 ft (point source size factor of 1.01) to 874 ft on the curved section of highway. It can be seen that for the straight section of highway, if either low beam is aimed .95° above the correct aim position, the detection distance will be greater than the detection distance for the nearly correct beam low beam position. In contrast, for the curved section of highway, detection distances greater than the detection distance for the nearly correct aim position are obtained only if the driver's side low beam or both low beams are aimed .95° above the correct aim position.

Figure 11 shows detection distances and percentages for a 23 CIL license plate located on the right and left side of a straight and a left-curved section of highway for the 25 beam misaim combinations. It can be seen that the low beam detection distances range from 519 ft to 1,116 ft when the license plate is located above the right edge of a straight section of highway, 612 to 1,355 ft when located above the left edge. The distances also range from 327 (point source size factor of 1.17) to 618 ft when the license plate is located above the

Driver Side \ Passenger Side		Reflector Material	● H .9° V .95°		H .9° ● V .95°		H 0° V .15°		V 1.25° ● H .9°		V 1.25° H .9° ●	
			Dist	%	Dist	%	Dist	%	Dist	%	Dist	%
Lowbeam Straight	● H .9° V .95°	Pris.	5390	150	4944	138	4830	134	4769	133	4751	132
		Enc.	4193	152	3829	138	3746	135	3701	134	3685	133
	H .9° ● V .95°	Pris.	4934	137	4166	116	3929	109	3781	105	3732	104
		Enc.	3816	138	3181	115	2997	108	2896	105	2847	103
	H 0° V .15°	Pris.	4810	134	3913	109	3592	100	3390	94	3313	92
		Enc.	3728	135	2984	108	2767	100	2622	95	2562	93
	V 1.25° ● H .9°	Pris.	4749	132	3758	105	3382	94	3137	87	3020	84
		Enc.	3679	133	2871	104	2613	94	2439	88	2356	85
	V 1.25° H .9° ●	Pris.	4729	132	3704	103	3303	92	3019	84	2896	81
		Enc.	3662	132	2818	102	2554	92	2356	85	2256	82
Highbeam Straight	● H .9° V .95°	Pris.	6389	95	6322	94	6544	98	6182	92	6128	92
		Enc.	5074	96	5017	95	5183	98	4878	92	4840	91
	H .9° ● V .95°	Pris.	6328	95	6253	93	6489	97	6104	91	6050	90
		Enc.	5023	95	4964	94	5137	97	4816	91	4772	90
	H 0° V .15°	Pris.	6549	98	6490	97	6692	100	6367	95	6320	94
		Enc.	5188	98	5137	97	5292	100	5013	95	4977	94
	V 1.25° ● H .9°	Pris.	6182	92	6097	91	6361	95	5921	88	5855	87
		Enc.	4878	92	4808	91	5007	95	4623	87	4572	86
	V 1.25° H .9° ●	Pris.	6133	92	6048	90	6318	94	5862	88	5790	87
		Enc.	4844	92	4769	90	4975	94	4578	87	4527	86

+ Correct Aim of Headlamp
● Actual Aim of Headlamp
Dist. - Distance (ft.) From the Object to the Driver for an Illuminance of 60 MOT
% - Distance Obtained for Actual Headlamp Misalignment Expressed as a Percentage of the Distance Obtained for the Average Headlamp Position
Pris. - Prismatic Sheeting Material
Enc. - Encapsulated Lens Sheeting Material

FIGURE 9 Detection distances and percentages for an overhead guide sign on a straight section of highway, high and low beam conditions, two different retroreflective materials, and 25 combinations of driver's and passenger's side headlamp misaims.

left edge of the left-curved section of highway, and 423 and 637 ft when located above the right edge. For the straight section of highway, if either low beam is aimed .95° above the correct aim position, the detection distance will be greater than the detection distance for the nearly correct aim position. For the curved section of highway, detection distances greater than the detection distance for the nearly correct aim position are obtained only if the driver's side low beam or both low beams are aimed .95° above the correct aim position. As indicated by the black shaded area, the detection distance will be reduced to less than 70 percent of the detection distance for the nearly correct low beam aim position if the driver's side low beam is aimed .9° to the right and 1.25° below the correct position and the passenger's side beam is aimed 1.25° below the correct aim position with a horizontal misaim of either .9° left or .9° right of the correct aim position.

In reviewing Figures 7 through 11, a few general observations may be made. For a given retroreflective material, the longest detection distance for the low beams is always observed when both low beams are identically aimed 0.9° left and 0.95° above the correct aim position. The longest detection distance for the high beams is always observed when both high beams are identically and nearly correctly aimed, and the shortest detection distances for both low and high beams are observed when both beams are identically aimed 0.9° right and 1.25° below the correct aim position. With the exception of the warning sign on the left side of the highway, the detection distances for the reflective targets investigated are always reduced to less than 90 percent if both beams (either high or low beams) are misaimed 1.25° below the correct aim position. Further it can be seen that the relative effect of beam misaim on detection distance is about the same for each of the three types of retroreflective sheeting materials.

Figure 12 shows maximum, minimum, and nearly correct aimed detection distances for all targets and investigated conditions. It can be seen that the shortest distances for the high beam condition are always higher than the longest distances for the low beam and that the high beam is much less sensitive to the horizontal and vertical misaim conditions investigated in this study than the low beams. Comparing the reflective materials shows that the shortest distance obtained for the encapsulated lens sheeting material is always about equal to the distance obtained for the nearly correct aim position for the enclosed or embedded lens sheeting material. Further,

Driver Side		Reflector Material	Passenger Side: H .9° V .95° Dist	%	H .9° V .95° Dist	%	H 0° V .15° Dist	%	V 1.25° H .9° Dist	%	V 1.25° H .9° Dist	%
Lowbeam Straight	H .9° V .95°	Pris.	1992	154	1827	142	1763	137	1734	134	1726	134
		Enc.	1500	154	1375	141	1325	136	1299	134	1295	133
	H .9° V .95°	Pris.	1822	141	1575	122	1462	113	1401	109	1388	108
		Enc.	1374	141	1196	123	1129	116	1092	112	1086	112
	H 0° V .15°	Pris.	1755	136	1454	113	1291	100	1196	93	1175	91
		Enc.	1320	136	1093	112	972	100	893	92	880	91
	V 1.25° H .9°	Pris.	1723	133	1386	107	1185	92	1045	81	998	77
		Enc.	1292	133	1042	107	881	91	769	79	743	76
	V 1.25° H .9°	Pris.	1714	133	1373	106	1162	90	998	77	957	74
		Enc.	1288	133	1030	106	862	89	738	76	701	72
Lowbeam Left Curve	H .9° V .95°	Pris.	874	117	868	116	833	112	799	107	797	107
		Enc.	698	118	693	117	666	113	642	108	638	108
	H .9° V .95°	Pris.	866	116	860	115	820	110	788	105	786	105
		Enc.	689	116	682	115	649	110	629	106	626	106
	H 0° V .15°	Pris.	805	108	796	107	747	100	703	94	698	93
		Enc.	633	107	626	106	592	100	560	95	555	94
	V 1.25° H .9°	Pris.	745	100	730	98	665	89	616	82	605	81
		Enc.	591	100	575	97	538	91	514	87	503	85
	V 1.25° H .9°	Pris.	735	98	719	96	637	85	585	78	564	76
		Enc.	572	97	555	94	514	87	479	81	472	80

┼ Correct Aim of Headlamp
• Actual Aim of Headlamp
Dist. - Distance (ft.) From the Object to the Driver for an Illuminance of 60 MOT
% - Distance Obtained for Actual Headlamp Misalignment Expressed as a Percentage of the Distance Obtained for the Average Headlamp Position
Pris. - Prismatic Sheeting Material
Enc. - Encapsulated Lens Sheeting Material

FIGURE 10 Detection distances and percentages for a post delineator on a straight and a curved section of highway, for low beam conditions, two retroreflective materials, and 25 combinations of driver's and passenger's side headlamp misaims.

the shortest distances obtained for the prismatic sheeting material are about equal to or longer than the distances obtained for the encapsulated lens sheeting material for the nearly correct beam misaim condition. Therefore, it would seem that the detrimental effect of misaimed beams on the detection distance of reflectorized targets may be almost totally offset by the use of brighter reflector material. However, Sivak and Olson (*12*) have discussed a number of studies which have shown that legibility is generally an inverted U-shaped function of luminance. Thus, there is concern that the selection of brighter reflectorized materials, which would increase detection distances, might have a negative effect upon recognition distance. In a recent study, Zwahlen et al. (*13*) has concluded that based upon average correct recognition distances and the number of correct and incorrect responses, the use of high reflective sheeting materials, such as prismatic sheeting material, combined with fairly high beam illumination conditions have only a small effect upon shape recognition. Therefore, it would appear that the use of brighter reflective materials, encapsulated lens or prismatic sheeting materials, in the design of reflectorized targets will likely offset the detrimental effect of misaimed beams on detection distance while causing only a small, practically negligible negative effect upon recognition distance.

Figure 12 also shows decision sight distance (DSD) for a selected design speed of 55 mph (interpolated from decision sight distances for design speeds of 50 and 60 mph (*1*)) and stopping sight distance (SSD) for a design speed of 55 mph (interpolated from stopping sight distances for design speeds of 50 and 60 mph (*14*)). The decision sight distance is defined as the distance required for a driver to detect a hazard in a cluttered roadway environment, recognize its threat potential, select an appropriate speed and path, and safely perform the necessary avoidance maneuver. The stopping sight distance (SSD) is defined as the distance which is traversed by a vehicle from the instant a driver sights an object for which a stop is necessary until the vehicle is stopped. Looking at Figure 12, it can be seen that, with the exception of detection distances for a vertical beam misaim of .95° above the correct aim position for the license plate on a straight section of highway, all of the distances obtained for the license plate (the only object investigated in this study which might require an immediate stop) are shorter than the minimum decision sight distance for an approach speed of 55 mph. The longest detection

Driver Side	Driver Side Aim	License Position	Passenger Side: ● H .9° V .95° Dist	%	Passenger Side: H .9° ● V .95° Dist	%	Passenger Side: H 0° V .15° Dist	%	Passenger Side: V 1.25° ● H .9° Dist	%	Passenger Side: V 1.25° H .9° ● Dist	%
Lowbeam Straight	● H .9° V .95°	Right*	1355	159	1238	145	1197	141	1182	139	1178	138
		Left**	1116	168	999	150	978	147	969	146	962	145
	H .9° ● V .95°	Right	1220	143	1047	123	979	115	947	111	937	110
		Left	966	145	789	119	750	113	729	110	711	107
	H 0° V .15°	Right	1168	137	949	112	851	100	792	93	779	92
		Left	923	139	713	107	665	100	641	96	617	93
	V 1.25° ● H .9°	Right	1144	134	893	105	769	90	685	80	662	78
		Left	902	136	681	102	618	93	590	89	572	86
	V 1.25° H .9° ●	Right	1138	134	881	104	743	87	649	76	612	72
		Left	890	134	654	98	579	87	549	83	519	78
Lowbeam Left Curve	● H .9° V .95°	Right	637	117	634	117	615	113	596	110	593	109
		Left	618	120	613	119	590	115	565	110	564	110
	H .9° ● V .95°	Right	630	116	626	115	603	111	580	107	575	106
		Left	609	118	604	118	577	112	554	108	553	108
	H 0° V .15°	Right	583	107	573	106	543	100	519	96	511	94
		Left	551	107	546	106	514	100	478	93	477	93
	V 1.25° ● H .9°	Right	539	99	529	97	480	88	461	85	453	83
		Left	477	93	470	91	422	82	381	74	376	73
	V 1.25° H .9° ●	Right	525	97	511	94	465	86	437	80	423	78
		Left	469	91	460	89	395	77	342	67	327	64

+ Correct Aim of Headlamp
● Actual Aim of Headlamp
Dist. - Distance (ft.) From the Object to the Driver for an Illuminance of 60 MOT
% - Distance Obtained for Actual Headlamp Misalignment Expressed as a Percentage of the Distance Obtained for the Average Headlamp Position
*Right - License Plate Located Above Right Edge Line
**Left - License Plate Located Above Left Edge Line

FIGURE 11 Detection distances and percentages for a 23 CIL license plate located on the right and the left side of a straight and a curved section of highway, for 25 combinations of driver's and passenger's side headlamp misaims.

distances observed for the license plate in a left-curved section of highway are 250 ft shorter than the minimum decision sight distance. Further, the shortest distances for a license plate located along either edge of a 2,000 ft radius (2.9°) left curve are equal to or below the required stopping sight distance for 55 mph. The rear of most motor vehicles is equipped with prismatic retroreflective devices in addition to a reflectorized license plate which would aid in the detection of a disabled vehicle along the edge of the highway if one is approaching from the rear. However, it should be noted that the results obtained would appear to indicate that if a driver were to approach the front of a disabled vehicle, which is usually not equipped with any retroreflective device other than possibly a reflectorized license plate, a driver may not be able to detect its presence until it is too late to bring his or her vehicle to a complete stop, especially if the vehicle is disabled in a 2,000 ft radius left-curved section of highway.

In the systematic study of horizontal and vertical misaim conducted by Bhise et al. (*2*), the horizontal misaim of low beams was found to have less effect upon the driver visibility criterion than the vertical misaim. Considering the isocandela distribution of the halogen 6054 beam used in this study, or any sealed low beam headlamps commonly used in the United States, this finding would be expected. The maximum horizontal dimension of each isocandela contour is 2 to 3 times larger than the corresponding maximum-vertical dimension. Comparing the detection distance calculated for a low beam misaim of .9° to the right and .95° up for the warning sign on the left side of a straight section of highway and the license plate on the same section of highway (see Figures 8 and 11) to a low beam misaim angle of .9° to the left and .95° up for the same targets (a horizontal shift of 1.8°), it can be seen that the differences between the two percentages are about 45 percent for the warning sign (3,774 ft or 160 percent down to 2,727 ft or 115 percent for prismatic sheeting material) and about 49 percent for the license plate (1,355 ft down to 1,047 ft). Comparing the detection distances calculated for a beam misaim of .9° to the left and .95° up with a beam misaim of .9° to the left and 1.25° down (a vertical shift of 2.2°) for the same signs, it can be seen that the difference between the two percentages is about 36 percent (2,727 ft down to 1,877 ft for prismatic sheeting material) for the warning sign on the left side of the highway and about 41 percent (789 ft down to 519 ft) for the license plate. It can be seen that the difference

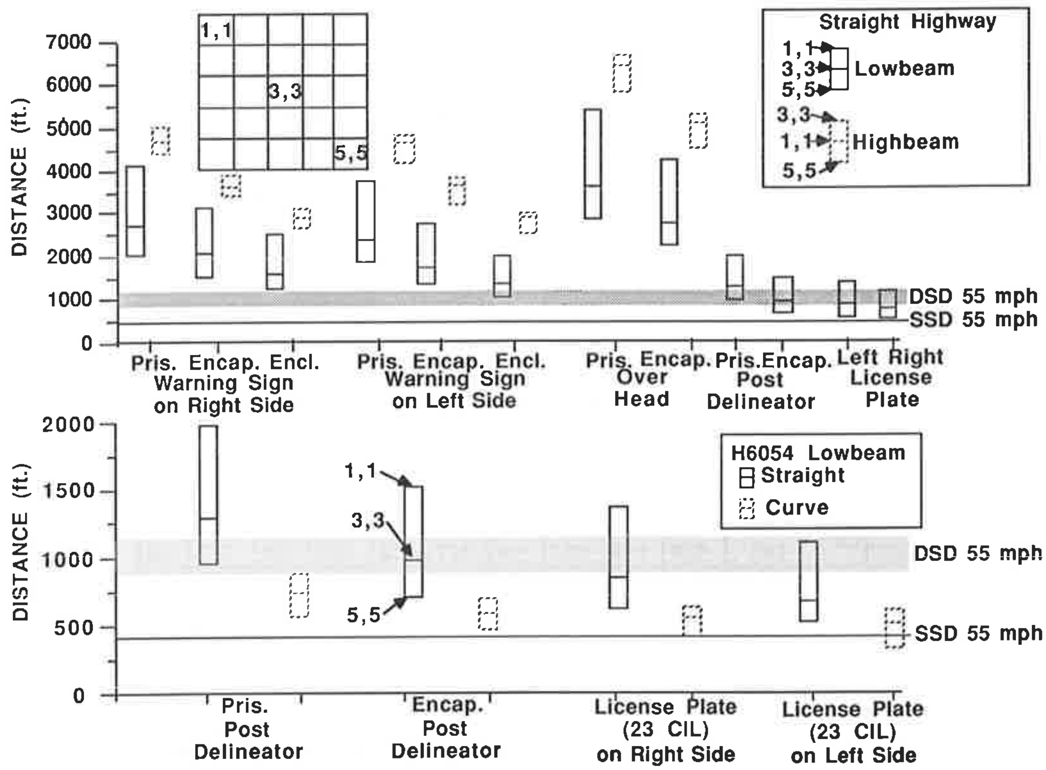

FIGURE 12 Maximum, minimum and nearly correct aimed beam detection distances for the five targets, three retroreflective sheeting materials (prismatic, encapsulated lens, and enclosed lens), high and low beam conditions, and for straight and left-curved sections of highway.

between the two percentages is 45 percent for the warning sign and 49 percent for the license plate when the horizontal misaim was changed by 1.8° and the percentages decreased by 36 percent for the warning sign and 41 percent for the license plate when the vertical misaim was changed by 2.2°. Conducting this same analysis for the overhead guide sign shows that a horizontal shift of 1.8° would result in a difference of 34 percent for the low beams and a vertical shift of 2.2° would result in a difference of 35 percent. Therefore, it appears that detection distance can be more sensitive to horizontal misaim than vertical misaim for specific geometric conditions: however, this seems to be the exception to the rule since the vertical misaim is, in general, more sensitive than the horizontal misaim for the majority of conditions.

Figure 11 shows that when both low beams are aimed 1.25° below the correct aim position, and the horizontal beam misaim is moved from .9° to the left to .9° to the right of the correct aim position, the horizontal change of 1.8° will reduce the detection distance by 38 ft for the license plate on the right side of the highway in the left-curved section, and 54 ft for the license plate on the left side of the highway in the left-curved section of highway. For a license plate in a 2,000 ft radius left-curved section, the detection distance is less than the decision sight distance for all the low beam misaim conditions. The decrease in the detection distance, due to this horizontal misaim, reduces the detection distances to those that are shorter than the stopping sight distance. These short reductions may be significant from a practical or safety point of view.

CONCLUSIONS

Vertically misaimed high and low beams have a larger effect on the detection distance of reflectorized targets than horizontally misaimed beams. However, the influence of horizontal beam misaims may not be negligible, suggesting that a correct aiming position of the beams in both the vertical and horizontal directions would be desirable. The detrimental effect of misaimed beams on detection distance can, in most cases, be totally or almost totally offset by the selection of a brighter reflector material (prismatic or encapsulated material). When measuring the aim of beams, it would appear to be important to measure both low beams and high beams (for vehicles with 4 headlamps), to determine the horizontal and vertical misaim and frequency distributions beyond plus or minus 1.9° (maybe up to 3° or 5°) and also to investigate any possible aiming relationships between the passenger side and driver side beams.

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