Effects of Headlamp Aim and Aiming Variability on Visual Performance in Night Driving

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This paper presents results of headlamp aim studies using the DETECT and CHESS models. The influence of horizontal and vertical aim of low beam headlamps and variability of aim on the visual performance of drivers was studied. In the first study, the DETECT model was used to predict sight distances to pedestrian targets for various horizontal and vertical aim conditions of low beams. The results showed that the sight distances are more sensitive to aim changes in the vertical direction than in the horizontal direction. Similar results were obtained in the second study using the CHESS model, which computes such performance measures as the percentage of targets detected, percentage of drivers discomforted, and figure-of-merits. The third study, again using the CHESS model, investigated the effect of variability in headlamp aim on the night visual performance of drivers. In this study, the CHESS model was run under seven different levels of headlamp aiming variability—ranging from the high variability represented by random misaim to the ideal condition of no misaim. The results showed that the performances increased monotonically from the worst case of aim variability to the best case aim.

During the past 15 years, Ford Motor Company's human factors engineers have conducted extensive research on night visibility. Their primary focus has been to develop computerized tools that can assist in the evaluation of vehicular headlamp systems. This paper presents results obtained from using two computer models, DETECT and CHESS, to evaluate headlamp aiming issues.

The DETECT model computes target-seeing distances (also referred to as visibility or detection distances) to pedestrian targets and pavement delineation lines under headlamp illumination. The model can predict the sight distances both under unopposed (when no oncoming vehicle glare is present) and opposed situations (when an oncoming vehicle glare is experienced by the observer driver in the form of "disability glare" which generally reduces the sight distances). In addition, the model is programmed to compute discomfort glare levels experienced by the two meeting drivers. More detailed information on the validation of the model and its operation details is available elsewhere (*1, 2*). In general, the sight distances predicted by the model were found to be within about 13 percent of the average field-observed seeing distances (*3*).

The Comprehensive Headlamp Environment Systems Simulation (CHESS) model includes major portions of the DETECT model in its core. The CHESS model evaluates headlight performance by computing measures of driver visual performance in simulated encounters under different night roadway environments. In each encounter, there are sight distance tests and a glare discomfort check. The succession of encounters constitutes a standardized test route. The basic output of CHESS is the figure-of-merit, which is the percentage of the total distance traveled by the simulated drivers, over the standardized test route, where the headlighting satisfies preselected vision performance criterion levels. CHESS will judge the visual environment to be adequate when, in a given simulated encounter (a random event defined by a set of road-environmental conditions and vehicle/driver characteristics), the calculated sight distance to pedestrians and to the road delineation, and the calculated discomfort glare experienced by an oncoming driver all satisfy preselected criterion levels. More detailed descriptions of the performance criteria and CHESS model are available elsewhere (*3, 4*).

One important variable that influences the effectiveness of headlamps is headlamp aim. This paper presents results of three studies using the DETECT and CHESS models to evaluate the following headlamp aim-related issues:

- Expected variations in low beam performance when headlamps are aimed at the SAE specified ±4 in. at 25 ft limits,
- Effect of horizontal and vertical aim on the overall performance of low beam headlamps, and
- Effect of variability in headlamp aim on the night visual performance of drivers.

STUDY 1

Objective

This study estimated the sensitivity of seeing distance and discomfort glare when the low beam headlamps are aimed with different combinations of vertical and horizontal misaim. These misaims are within the range of the aiming tolerance specified in the SAE J599 standard (*5*).

Method

The DETECT model was used to predict seeing distances to a pedestrian target illuminated by type 2A1 halogen low beams (H4656—small rectangular sealed headlamp) under the following conditions on a straight level two-lane roadway:

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Aim Description	*Left Headlamp Aim*		*Right Headlamp Aim*	
	Horizontal	*Vertical*	*Horizontal*	*Vertical*
Both aimed up	0 in. right	4 in. up	0 in. right	4 in. up
Perfect aim	0 in. right	0 in. up	0 in. right	0 in. up
Both aimed down	0 in. right	4 in. down	0 in. right	4 in. down
Right lamp aimed left	0 in. right	0 in. up	4 in. left	0 in. up
Right lamp aimed right	0 in. right	0 in. up	4 in. right	0 in. up
Both aimed right	4 in. right	0 in. up	4 in. right	0 in. up
Both aimed left	4 in. left	0 in. up	4 in. left	0 in. up

Note that the aim is measured in inches at 25 ft (1 in. at 25 ft equals 0.19 degree).

The conditions describing the simulations were as follows:

- Pedestrian target: 6 ft high, 7 percent reflectance, located on the right edge of a 12-ft wide lane;
- Pavement reflectance: 6 percent;
- Ambient luminances: 0.001 fL (pavement), 0.005 fL (sky);
- Observer driver: 35 years old, 50th percentile contrast threshold.

The opposed driving evaluations were conducted with an oncoming vehicle equipped with the same headlamps and aim as that of the observer vehicle. This oncoming vehicle was placed at a 400 ft separation distance from the observer car.

Results

Unopposed Situation

Figure 1 presents sight distances to the pedestrian target for three different vertical aims under an unopposed driving condition. When the low beam headlamps are aimed perfectly (both headlamps at 0 in. right, 0 in. up), the driver can see the 7 percent reflectance pedestrian located on the right edge of the lane at a distance of 279 ft from the observer headlamps. When the headlamps are aimed down at 4 in. at 25 ft (about 0.8 degree down), the sight distance decreases to 195 ft. Conversely, if the headlamps are aimed up 4 in. at 25 ft (about 0.8 degree up), the sight distance increases to 342 ft. Thus, within the ±4 in. at 25 ft SAE aiming tolerance, the sight distance spread is 147 ft.

Figure 2 shows the effects of misaiming left and right while vertical aim is kept perfect (0 in. up at 25 ft). The top bar shows the sight distance of 279 ft with no misaim (as in Figure 1). Aiming only the right headlamp 4 in. to the left (4 in. at 25 ft) the sight distance goes up slightly to 292 ft. The increase in sight distance was due to shifting the hot spot of the low beam (which is about 2 degrees to the right of the headlamp axis) closer to the pedestrian. When the right headlamp is aimed the same amount to the right, the sight distance drops to 261 ft. The next two cases show results when both headlamps are misaimed by 4 in. at 25 ft in the same direction. Thus, as the horizontal aim of the headlamps is varied within the SAE limits of ±4 in. at 25 ft, the spread of sight distance is 41 ft. This is substantially lower than the 147 ft spread obtained over the vertical aim limits shown in Figure 1. These data clearly indicate that sight distance performance in an unopposed situation is more sensitive to changes in vertical misaim than to changes in horizontal misaim.

Opposed Situation

Figure 3 presents sight distances to the pedestrian targets under both the unopposed and opposed driving situations for the three vertical aims shown in Figure 1. The sight distance to a pedestrian target under perfect aim decreases from 279

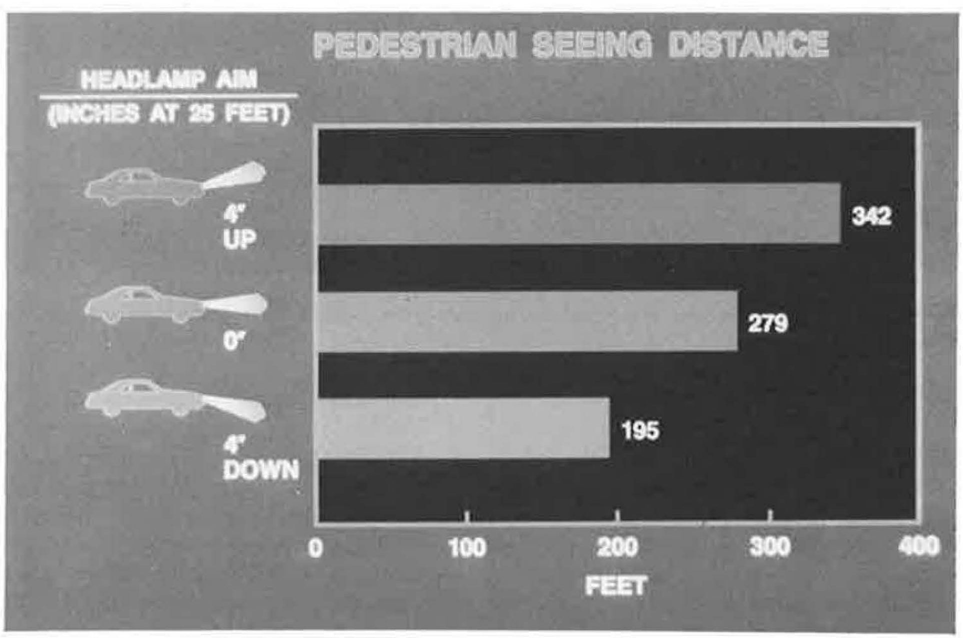

FIGURE 1 Effect of changes in vertical aim on pedestrian sight distances under unopposed driving situation.

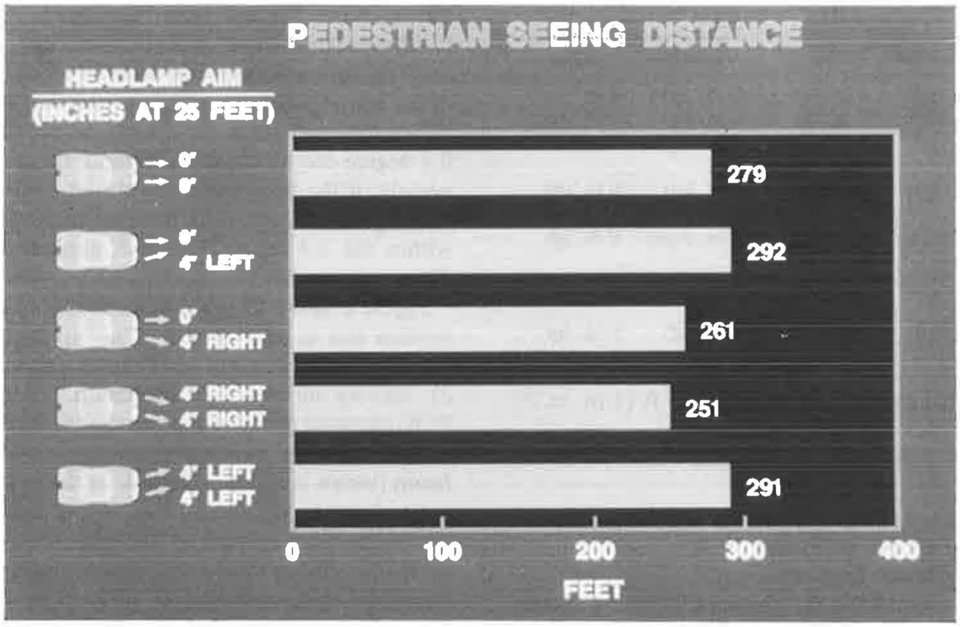

FIGURE 2 Effect of changes in horizontal aim on pedestrian sight distance under unopposed driving situation.

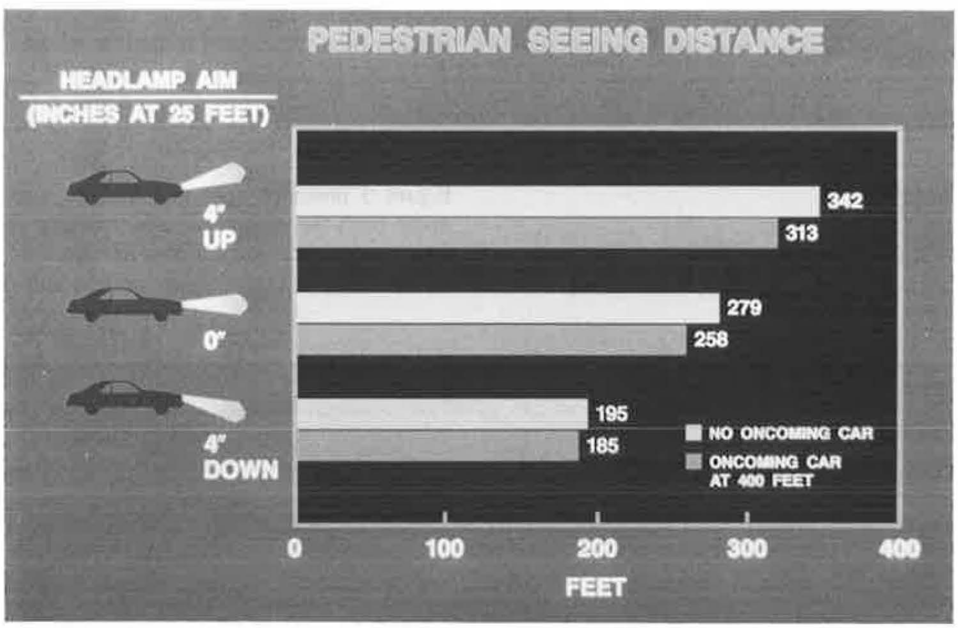

FIGURE 3 Effect of changes in vertical aim on pedestrian sight distance under opposed driving situation.

ft in an unopposed situation to 258 ft in an opposed situation (when an oncoming car with similar equipment and aimed headlamps is located at 400 ft). The reduction is due to the "disability" glare effect (modeled by using Fry's veiling glare expression (*1*)).

The DETECT model also computed the discomfort experienced by the driver in the oncoming vehicle. The discomfort glare was measured by computing the value of discomfort index based on a 9-point discomfort scale defined by DeBoer (*1, 2*). Figure 4 presents the discomfort glare levels experienced by the oncoming driver for the three vertical misaim levels. The oncoming driver's eye was assumed to be at an adaptation level of 0.1 fL. The figure shows that with perfect aim, the computed value of the DeBoer discomfort index is about 4 units, which can be classified as "slightly discomforting." With the low beam headlamps aimed upwards 4 in.

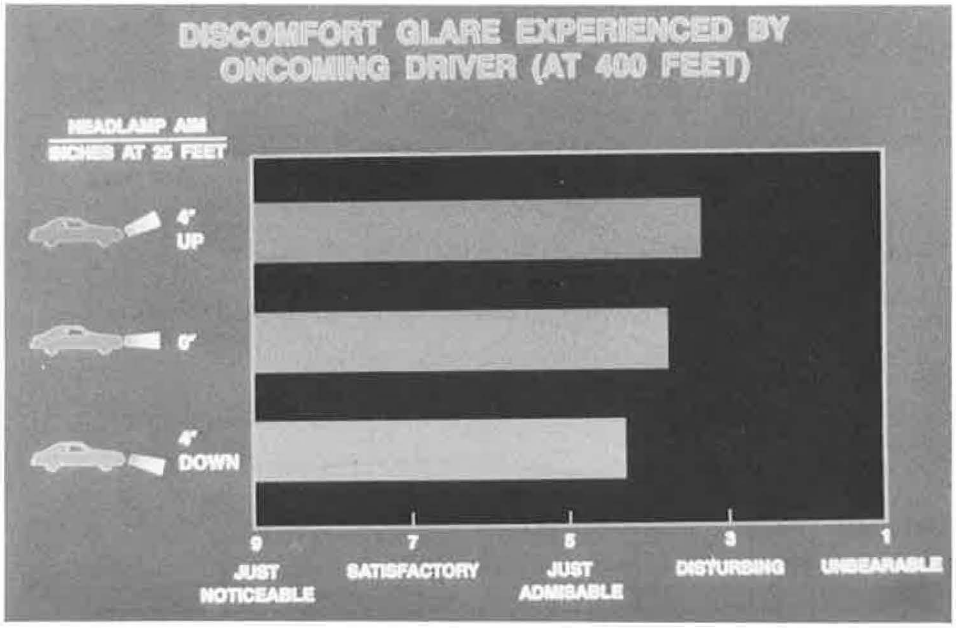

FIGURE 4 Effect of changes in vertical aim on discomfort glare experienced by the oncoming driver.

at 25 ft, the discomfort level increased to the point of being "disturbing." Conversely, aiming headlamps down reduced the discomfort level.

STUDY 2

Objective

This study was conducted to determine the effect of horizontal and vertical aim on the performance of low beam headlamps using the CHESS model.

Method

A series of 35 CHESS runs was made. In each, both headlamps of the observer vehicle were aimed in a preselected combination of horizontal and vertical positions; the 35 runs involved combinations of the following:

- Seven horizontal levels (measured in inches at 25 ft): 12 in. left, 8 in. left, 4 in. left, 0 in., 4 in. right, 8 in. right. 12 in. right.
- Five vertical aim levels (measured in inches at 25 ft): 8 in. down, 4 in. down, 0 in., 4 in. up, 8 in. up.

In all the runs, the headlamps of the opposing vehicle were perfectly aimed.

Results

Figures 5 through 10 present results obtained from these runs. Figure 5 presents the figures-of-merit (FOMs) for the 35 aim combinations of the observer vehicle headlamps. In this figure, FOMs obtained for each vertical aim level are joined by a curve. Thus, each curve predicts the effect of changes in horizontal aim for a given level of vertical aim. The curves, in general, are relatively constant (or flat) for horizontal aim between 4 in. left to 12 in. left. This indicates that overall performance of the low beam system would not be substantially influenced by changes in horizontal aim. The relative closeness of the curves for 0 in. up, 4 in. up, and 8 in. up indicates that vertical aim between 0 in. and 8 in. up should not affect the overall performance of the low beam system.

However, the large separations between the 0 in. up, 4 in. down, and 8 in. down curves show that if the headlamps are aimed downward, the overall performance should drop considerably.

As a general rule in interpreting the above results, two FOMs must differ by at least 2.0 points to be considered significantly different on a statistical basis (at the 90 percent confidence level).

Figures 6 through 10 illustrate how the three components of the FOM, the percentage of delineations and pedestrians detected and the percentage of discomforted drivers, vary with changes in horizontal and vertical aim. The relatively constant nature of the curves in Figures 6 through 9 indicates that visibility of delineation and pedestrians under both unopposed and opposed situations is less affected by changes in horizontal aim as compared to changes in vertical aim. Figure 10, however, predicts that the percentage of discomforted drivers should increase as the horizontal aim is moved left (toward the oncoming drivers) or as the vertical aim is moved up.

Conclusions

On the basis of data presented in Figures 5 through 10, it appears that, for the H4656 low beam pattern used in this

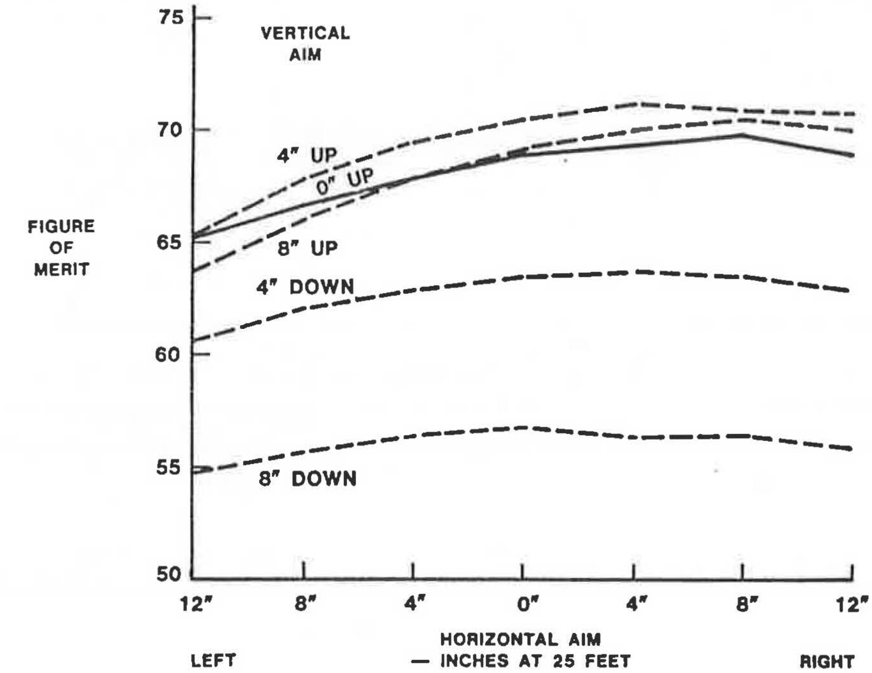

FIGURE 5 Figure-of-merit of H4656 low beam as a function of aim.

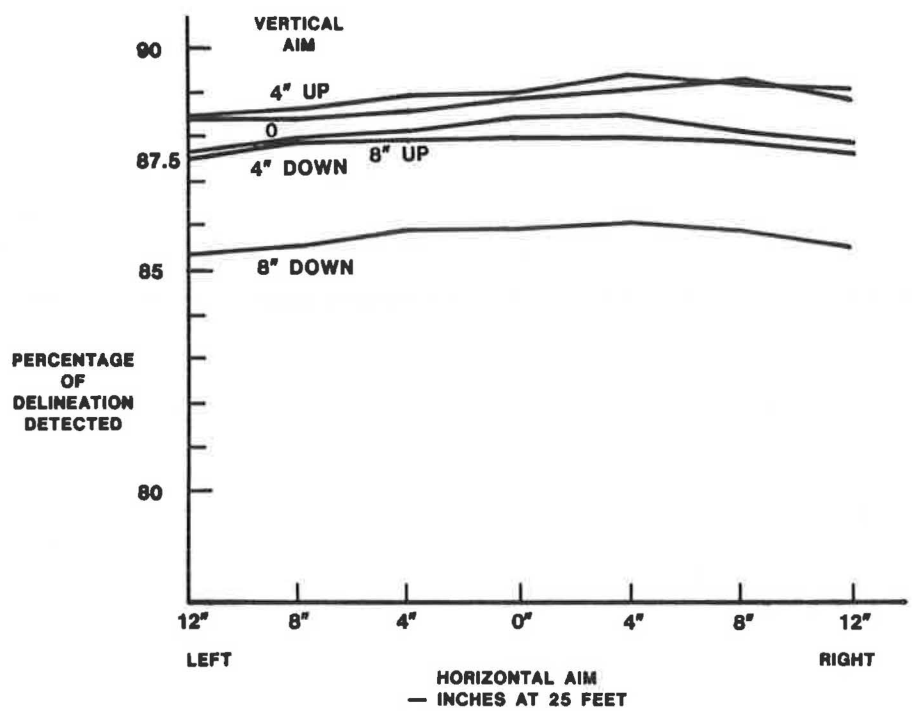

FIGURE 6 Percentage of delineation detected as a function of aim (unopposed).

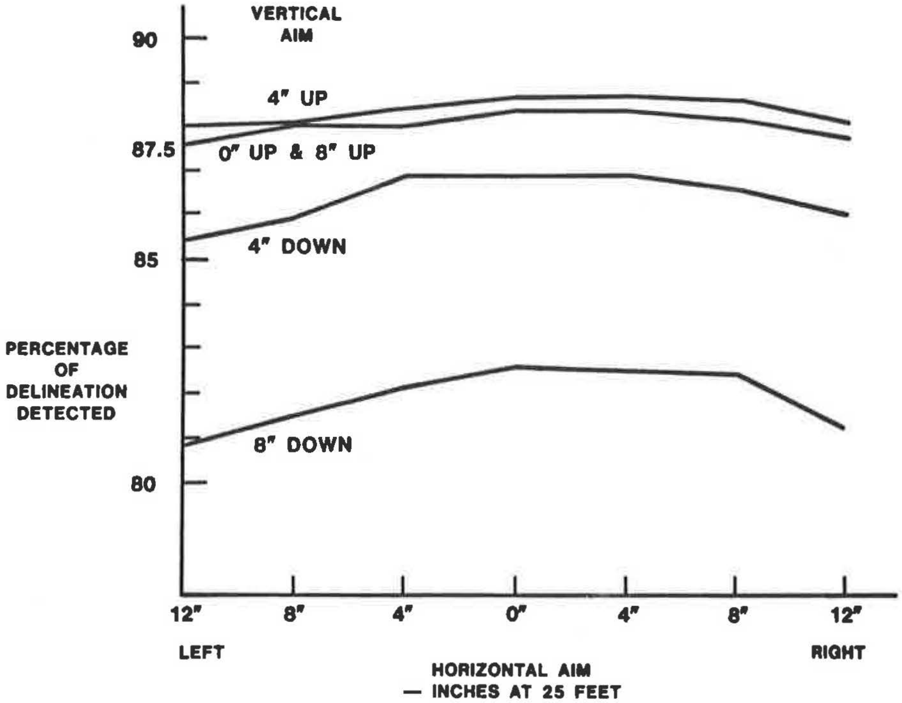

FIGURE 7 Percentage of delineation detected as a function of aim (opposed).

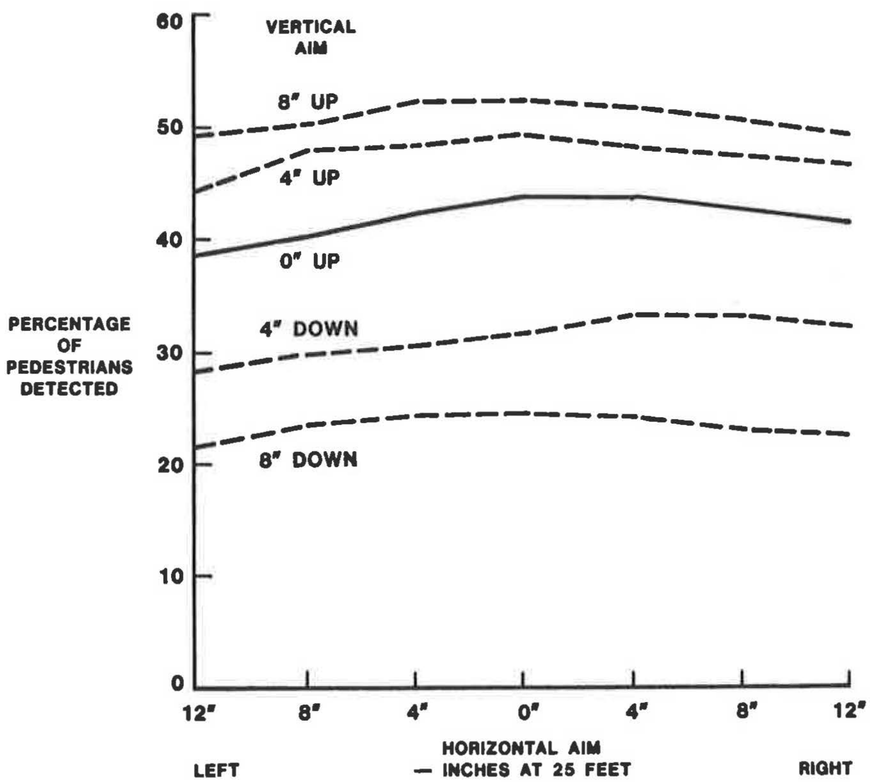

FIGURE 8 Percentage of pedestrians detected as a function of aim (unopposed).

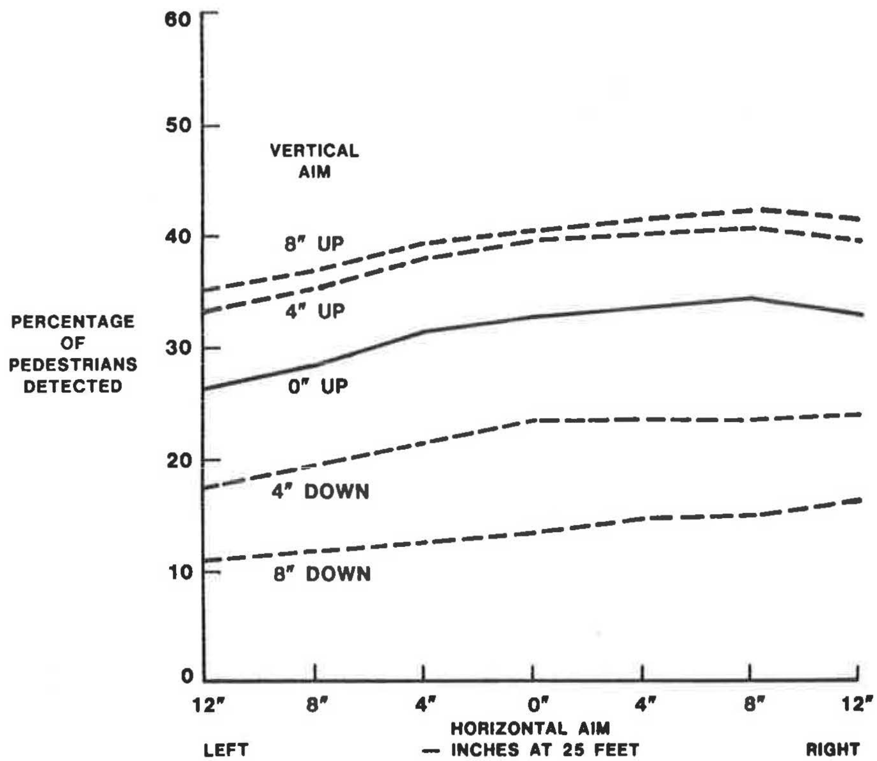

FIGURE 9 Percentage of pedestrians detected as a function of aim (opposed).

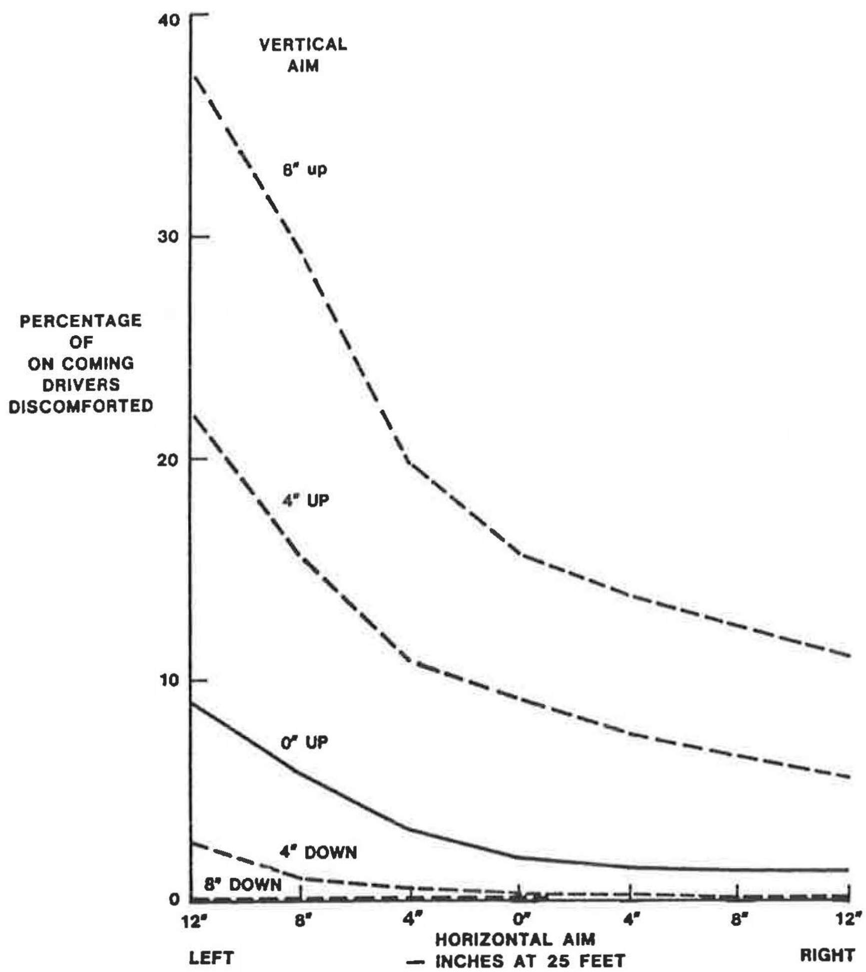

FIGURE 10 Percentage of oncoming drivers discomforted as a function of aim.

exercise, the headlamp performance is less sensitive to changes in horizontal misaim between 4 in. left and 12 in. right. This suggests that even if some small changes in beam patterns occur in the future due to production or assembly tolerances, the horizontal aiming capability may not be needed. On the other hand, any refinements in the vertical aiming capability of headlamps would be useful in improving headlamp performance.

STUDY 3

Objective

This study was conducted to determine the effect of stringency in the control of aim (the aiming tolerance) on low beam performance.

Method

A set of seven CHESS model runs, using H4656 low beams, was conducted. The seven aiming conditions, from least stringent to most stringent aim tolerance, are presented below.

- Random Aim—This condition assumed the headlamps to be randomly misaimed to the extent determined by Olson in his road study (*6*). This aim had a mean of 0 degree horizontally and 0.25 degree down in the vertical direction. The standard deviations were 0.78 degree horizontal and 1.00 degree vertical.
- SAE Horizontal Only—This case assumed that the horizontal aim of the headlamp can be held within the current SAE specifications (SAE J599, May 1981 specifies a range of misaim of ±4 in. at 25 ft (±0.76 degree) for inspection purposes). The vertical aim, however, was allowed to drift as in the current random misaim. The mean location of the headlamp was assumed to be 0 degree horizontal and 0 degree vertical. The standard deviations of the aim were assumed to be 0.253 degree horizontal and 1.00 degree vertical (*6*). The value of 0.253 degree for the horizontal standard deviation was based on the assumption that the SAE aim limit of 4 in. at 25 ft (equal to 0.76 degree) encompasses three units of standard deviation.
- UMTRI Measured New Car Aim—This case was based on Olson's survey for NHTSA (*6*). In this survey, Olson found that current year model cars at the time of the study (1984) had a mean headlamp aim at 0 degree horizontal and 0 degree vertical, and standard deviations of 0.53 degree horizontal and 0.77 degree vertical.
- SAE Vertical Only Aim—This case assumed that headlamps were aimed within SAE limits in the vertical direction, but the horizontal misaim was maintained at a current random aim level. For this situation, the mean position of the headlamps was maintained at 0 degree horizontally and 0 degree vertically. The standard deviations were 0.78 degree horizontally (*6*) and 0.253 degree vertically. The 0.253 degree vertical standard deviation was developed based on the assumption that three standard deviation limits can be contained within the present 4 in. limit at 25 ft SAE specification.
- SAE Aim Specifications—This case assumed that the headlamps were aimed with a mean of 0 degree horizontally and 0 degree vertically and with standard deviations of 0.253 degree (1.33 in. at 25 ft) horizontally and 0.253 degree (1.33 in. at 25 ft) vertically. The present SAE tolerances (*5*) of ±4 in. at 25 ft in both horizontal and vertical directions were assumed to be equal to ±3 standard deviations.
- NHTSA Proposed Requirements—This case assumed the same tolerances proposed in Docket 85-15, Notice 5, Section 7.7.5 (*7*). The mean headlamp aim location was assumed to be 0 degree, 0 degree with standard deviations of 0.12 degree (0.67 in. at 25 ft) horizontally and 0.06 degree (0.33 in. at 25 ft) vertically. The standard deviations were obtained by assuming that the NHTSA proposed tolerance bands (±2 in. at 25 ft horizontal and ±1 in. at 25 ft vertical) equal three standard deviations in each direction.
- Perfect Aim—This condition assumed that each headlamp was aimed perfectly, (along the H-V axis with 0 degree horizontal and 0 degree vertical mean) and with zero standard deviation in horizontal and vertical directions, 0 degree, 0 degree.

The seven aim conditions are graphically displayed in Figure 11.

Results

Table 1 defines the seven aiming conditions and presents the CHESS results. The table describes each aiming condition, the aiming tolerances, and the parameters used to represent the aiming conditions as inputs to the CHESS model. The last two columns provide FOM values obtained from the CHESS runs and percent changes relative to the figure of merit for Condition 1 (also see Figure 12).

Comparing the improvements in FOMs gained by reducing the aiming variability, a measure called percent change in

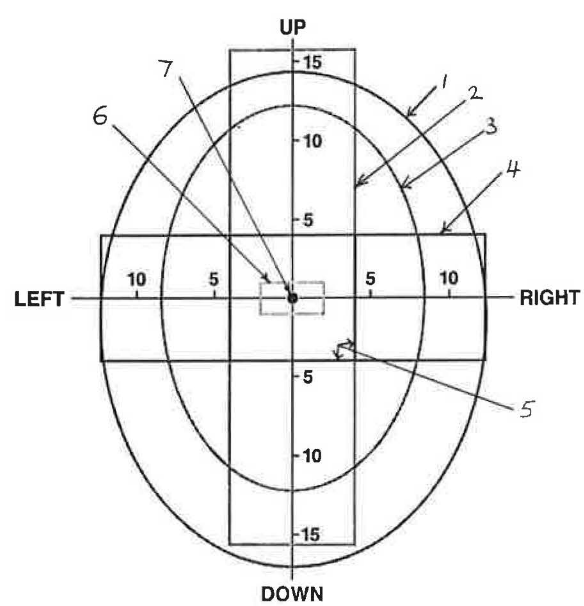

FIGURE 11 Tolerance envelopes for seven cases. Note: 1 = Random aim; 2 = SAE horizontal only aim; 3 = UMTRI measured new car aim; 4 = SAE vertical only aim; 5 = SAE aim specifications; 6 = NHTSA proposed; and 7 = Perfect aim.

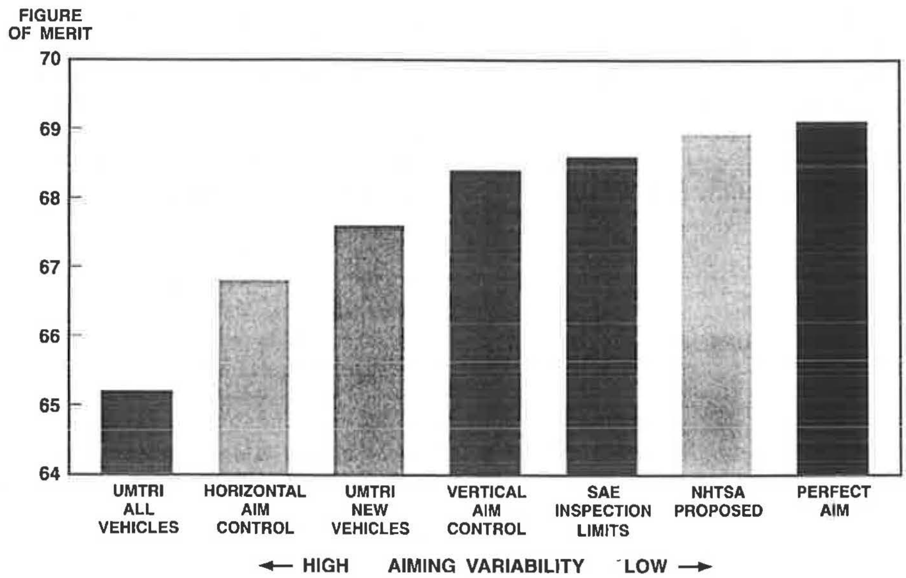

FIGURE 12 Figure-of-merit for the seven aim conditions.

TABLE 1 SUMMARY OF AIMING CONDITIONS AND CHESS MODEL RESULTS

	Aiming Tolerance (in. at 25 ft)		Aiming Parameters for CHESS Runs: Mean (deg.)		Aiming Parameters for CHESS Runs: Standard Deviation (deg.)			
Aiming Condition	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Figure of Merit	Percent Change in Figure of Merit (69.1–65.2%)
Random aim (from 1984 UMTRI Survey; includes all vehicles)	±12	±16	0.0	−0.25	0.78	1.00	65.2	0.0
SAE horizontal only (horizontal aim within ±4 in. at 25 ft)	±4	±16	0.0	0.0	0.25	1.00	66.8	41.0
UMTRI new vehicle aim (from 1984 survey)	±8	±12	0.0	0.0	0.53	0.77	67.6	61.5
SAE vertical only (vertical aim within ±4 in. at 25 ft)	±12	±4	0.0	0.0	0.78	0.25	68.4	82.1
SAE specs (both horizontal and vertical within ±4 in. at 25 ft)	±4	±4	0.0	0.0	0.25	0.25	68.6	87.2
NHTSA proposal (Doc. 85-15, N5)	±2	±1	0.0	0.0	0.12	0.06	68.9	94.9
Perfect aim	0	0	0.0	0.0	0.0	0.0	69.1	100.0

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FOMs was computed. Values of this measure are presented in the last column of Table 1. This percentage change is computed by assuming that the random aim condition represents the low anchor point of 0 percent, and the perfect aim condition represents the high anchor point of 100 percent. This measure helps in understanding the relative improvement in FOM that can be obtained by using these points. Thus, the table shows that 87.2 percent of the maximum improvement in the FOM can be obtained if all headlamps are aimed and maintained within the SAE specification, and 94.5 percent of the improvement can be obtained by holding aim to the NHTSA proposed aim requirements.

Figure 13 presents a bar chart showing the percent change in FOM obtained for the seven conditions. By observing the relative heights of the columns, it is clear that as the aim variability is decreased (in the successive columns to the right) the heights of the bars increase, but at a decreasing rate. This is a very important finding. Thus, in determining future aiming tolerances, it must be realized that very stringent aiming tolerances will not provide substantially greater benefits as compared to those achieved by conforming to the existing SAE specifications.

CONCLUSIONS

The major conclusions from the three studies presented are as follows:

- Vertical misaim is much more important than horizontal misaim.
- FOMs are very insensitive to horizontal misaim in the range of 4 in. left and right. This indicates the possibility of fixing horizontal aim and eliminating provisions for horizontal aim adjustment.

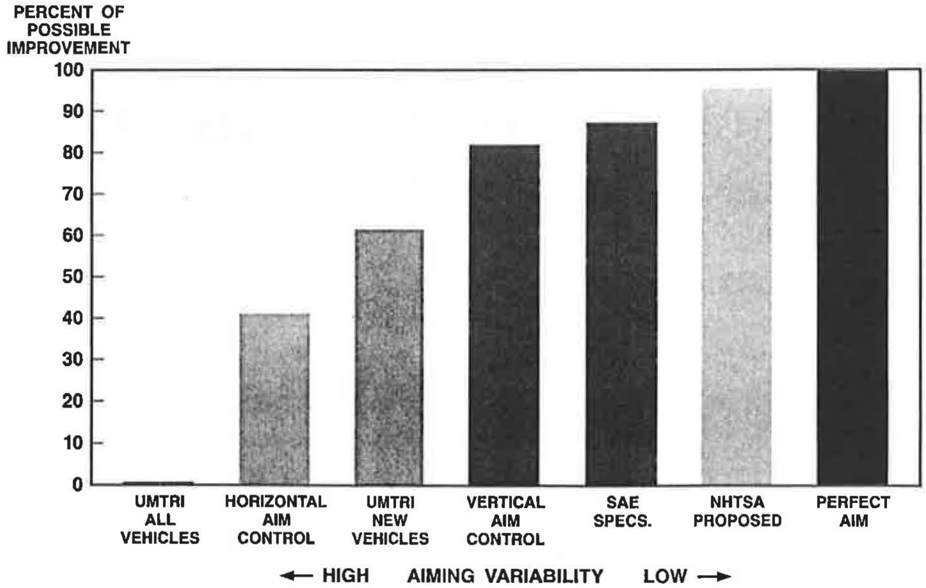

FIGURE 13 Percent change (or possible improvement) in figure-of-merit as aiming variability is decreased from UMTRI measured aim to perfect aim.

- Reductions in the allowable range of misaim beyond that referenced in the SAE standards (±4 in.) will produce only slight increases in performance. Thus, the present range of ±4 in. for inspection (specified in SAE J599) is adequate and should not be reduced.

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