SOME OPERATIONAL CONSIDERATIONS AFFECTING THE PERFORMANCE OF CURRENT AND PROPOSED HEAD-LAMP BEAMS

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A digital computer simulation was used to evaluate some factors that determine the overall effectiveness of current and proposed beams. Specifically, simulation was used to derive predicted visibility distances for a typical U.S. low beam and a proposed midbeam, with correct aim and with 1-deg (0.017-rad) upward or downward misaim. This demonstrated that aiming errors of this amount significantly affect a driver's visibility and the glare intensities to which opposing drivers are exposed. The midbeam offered a 20 percent increase in visibility of a target located at the right edge of the lane on a 2-lane road compared to the present low beam when the beams were correctly aligned. Because the midbeam provides greater visibility than the low beam, it was shown that it is appropriate to dim earlier from high beam to midbeam than to low beam, thereby obtaining better visibility and earlier reduction of high-beam glare. Use of the midbeam as the major meeting beam would make it more feasible to increase the intensity of the high beam. An examination of glare intensities from the beams in rearview mirrors showed the importance of lamp aim and mirror reflectivity to glare discomfort. For the conditions studied, it was concluded that the midbeam offers a satisfactory increase in visibility compared to the low beam and does not significantly increase glare if lamp aim is adequately controlled.

•ALTHOUGH the role of vehicle headlighting in highway crashes has not been determined, it is generally agreed that night visibility needs to be improved on those roads where fixed lighting is not available. To improve visibility in night driving, there has been a continuing evolution in head-lamp performance. Changes have been made recently in both American beams and European beams, where there are significant differences. (For example, the maximum permitted intensity of European high beams is 300 000 cd; in the United States it is 75 000 cd.) The changes have been accomplished by increasing intensities and changing the light distribution. High intensities from head lamps are now possible because of more efficient vehicle generating systems and halogen bulbs. Because inability to produce enough illumination from high beams is no longer a significant problem, the poorer performance of low or meeting beams has been highlighted. The need to improve the visibility distance when opposing vehicles meet has influenced further work to improve the meeting beam. In the United States, this has led to the concept of a 3-beam system consisting of a low, mid, and high beam.

A number of factors determine overall beam performance including visibility, glare effects, aiming effects, and the control switch.

COMPUTER SIMULATION

A major obstacle in the development of improved headlighting systems has been the lack of methodology to evaluate such systems. Conventionally, this is done by field

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tests in which vehicles are driven toward each other and measures of visibility of certain types of targets are obtained. Although field testing is a necessary part of head-lamp development, it has problems normally associated with experimental techniques. For example, maintenance of head-lamp aim from one test run to another and knowledge of the precise aim used at any time are difficult to achieve. Also, the number of variables that can be studied is limited. For example, the number of beam patterns that can be evaluated depends on the number available in hardware form and on time and cost constraints. For these and other reasons we have developed an analytical technique by which head-lamp performance can be evaluated. The advantages this method has over experimental tests include (a) complete control over all prevailing conditions, (b) precise aim of the lamps, (c) evaluation of beam patterns that are not available in hardware form, (d) low cost, and (e) fast evaluations. But, such a procedure must be validated.

Therefore, a series of field studies were conducted to evaluate the effects of a number of important parameters concerning beam intensity distributions, target location, target reflectance, lateral separation distance between vehicles, and longitudinal distance between the vehicles in a simulated meeting situation (1). The effects were found in terms of target visibility distances. The targets used in these tests are of the type shown in Figure 1. The observers had to detect the target and identify the position of the square with respect to the horizontal line. Target visibility tests, then, emphasized the orientation of the target. A computer simulation model was simultaneously developed to make predictions of the mean visibility of the target before and after the meeting point.

In its present form the computer simulation is limited to straight, level roads having a constant pavement reflectivity. Approaching vehicles move on parallel paths at constant speeds. Each vehicle may carry up to 5 head lamps. A 3-stage model of adaptation and recovery from glare effects is used. The model is described in greater detail by Mortimer and Becker (2, 3).

Validity of Computer Simulation

The validity of the computer simulation is assessed by how the visibility distances predicted by the model match those obtained in the field experiments. Examples of such comparisons are shown in Figures 2 and 3. Figure 2 shows the comparison between computer simulation and experimentally obtained mean visibility distances for the target having 12 and 54 percent reflectances and positioned on the right of the lane. Both vehicles were equipped with conventional U.S. 6014 low beams. Figure 3 shows the comparison between experimental and computer simulation results for the target having a 12 percent reflectance and positioned on the left side of the lane. Both vehicles were equipped with low and high beams and had a 14-ft (4.27-m) lateral separation. Across the variety of these conditions, there is agreement between the simulation and the experimental results. Therefore, the computer simulation can be used to evaluate the effects on visibility of various head-lamp beams and other conditions, such as the head-lamp aim.

Effects of Aim on Low-Beam and Midbeam Performance

In a recent study in which the accuracy of aiming head lamps by service outlets was measured, it was found that head lamps were frequently aimed outside the Society of Automotive Engineers (SAE) specification (4). SAE Recommended Practice J-599c states that head lamps should be aimed within ±4 in. at 25 ft (±10 cm at 7.6 m), or approximately ±0.8 deg (±0.014 rad), of nominal aim. The following table gives the percentage of head lamps that were misaimed in the horizontal or vertical or both. Up to 35 percent of head lamps were misaimed by the 24 service stations and 8 automobile dealerships in the Ann Arbor, Michigan, area where the study was conducted.

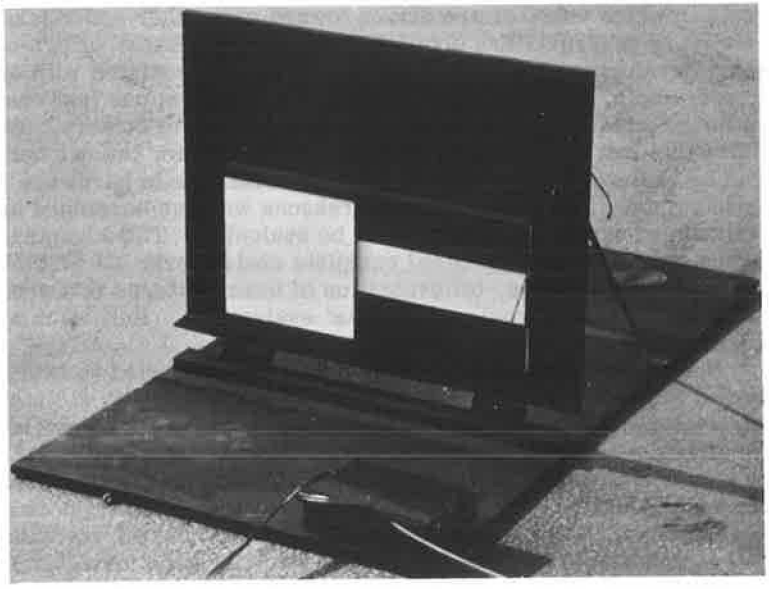

Figure 1. Field experiment target.

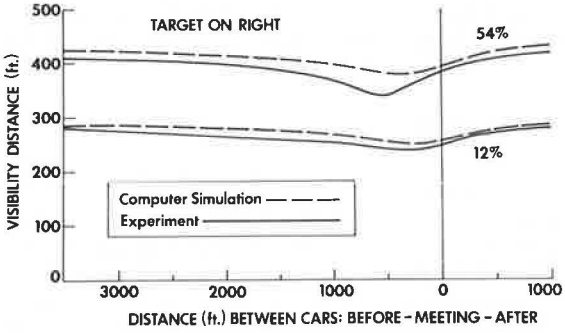

Figure 2. Experiment and simulation reflectance comparison for target on right of lane.

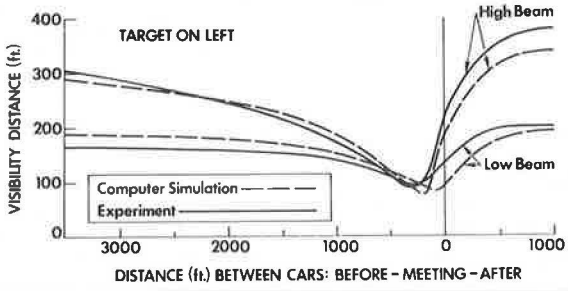

Figure 3. Experiment and simulation reflectance comparison for target on left of lane.

Direction of Misaim	Percent
Horizontal	18
Vertical	26
Horizontal and vertical	35

In the same study, the effect of vehicle loading was examined for a number of different automobiles and a pickup truck. The following table gives the change in the vertical aim (inches at 25 ft) of the head lamps that occurred when the vehicles were loaded to full capacity. Initially, the vehicle had a 150-lb (68-kg) driver and a full gas tank. The change in vertical aim exceeded the SAE recommendation in each case.

Vehicle	Change
Compact	+6.5
Sedan	+5.8
Station wagon	+4.3
Pickup truck	+5.8

To determine the effect of changes in vehicle aim of 1 deg (0.017 rad) on both visibility and glare, computer simulation analyses were made for low-beam and midbeam performance. Figure 4 shows the predicted visibility distances of a target having a 12 percent reflectance and located on the right side of the lane of a 2-lane road. Both vehicles were equipped with typical U.S. 6014 low-beam head lamps. The photometric test-point values of low beams and midbeams are given in Table 1. The effect of a 1-deg (0.017-rad) upward aim on the low beams of 2 cars meeting each other is to increase visibility. Conversely, the effect of a 1-deg (0.017-rad) downward aim on both vehicles is to substantially reduce visibility.

Figure 5 shows the same computer simulation data involving the midbeam. This composite beam is made up of 2 low-beam lamps and a type 3 lamp mounted on the left of the car, whose high intensity zone is sharply cut off just below the horizontal and its left edge at the vertical (Table 1). In Figure 5 where one midbeam meets another midbeam, there is an increase of approximately 20 percent in visibility compared to low beam meeting low beam. If a midbeam system is introduced, vehicles equipped with midbeams will meet vehicles equipped with low beams. Figure 5 shows that the driver of the vehicle with low beams will not suffer much loss of visibility. Figure 5 also shows the effects on visibility of meetings between vehicles with midbeams that are aimed 1 deg (0.017 rad) up or down, compared to normal aim. The effect of 1 deg (0.017 rad) upward misalignment is a small increase in visibility that is removed close to the meeting point. As with the low beam, a 1-deg (0.017-rad) downward aim is a large loss of visibility.

These data suggest that the midbeam may offer a worthwhile gain in visibility over the low beam. Obviously, this increase in visibility depends on the beam patterns of the composite midbeam and the low beam. Although the data shown here indicate that a 20 percent increase in seeing distance may be expected, other evaluations of various experimental low beams and midbeams found midbeam gains in seeing distance of as little as 10 percent (5).

Comparison of Figures 4 and 5 indicates that if the low beam is aimed 1 deg (0.017 rad) up, substantially the same visibility distances are obtained as in meeting situations between vehicles equipped with correctly aimed midbeams. This might suggest that it is necessary only to increase the intensity of the current low-beam configuration or to change its aim specification or both. However, it is also necessary to examine the effects of discomfort glare during night meeting situations to determine the performance of head-lamp beams.

Direct Glare Effects of Meeting and High Beams

The computer simulation is a convenient means of determining the glare intensities to which the drivers are exposed. The intensities directed at the driver's eyes from

Figure 4. Simulation visibility distances for low-beam meetings.

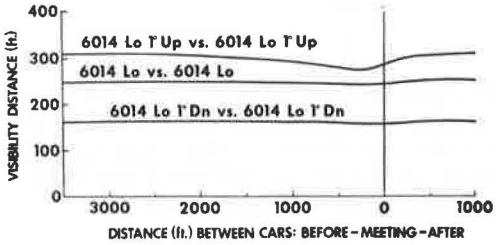

Figure 5. Simulation visibility distances for midbeam meetings.

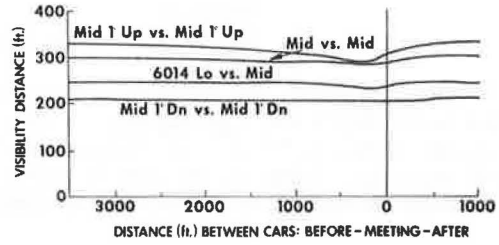

Table 1. Photometric test-point values.

Test Points (deg)	U.S. 6014 Low Beam (cd) Test	U.S. 6014 Low Beam (cd) Standard[a]	Experimental Type 3 Beam (cd)
1 up, 1.5 left	178	<700	281
0.5 up, 1.5 left	333	<1,000	422
0.5 down, 1.5 left	1,180	<2,500	722
1.5 up, 1 right	412	<1,400	612
0.5 up, 1.3 right	1,340	<2,700	11,120
0.5 down, 1.5 right	9,000	20,000 to 8,000	35,760
1 down, 6 left	960	>750	631
1.5 down, 2 right	26,300	>15,000	28,240
1.5 down, 9 left	1,160	>750	766
1.5 down, 9 right	3,220	>750	3,256
4 down, 4 right	11,830	<12,500	976
2.5 right, 2 down	28,000		–
4 right, 1 down	–		

Note: 1 deg = 0.017 rad.

[a]SAE specification J-579b for low beams.

Table 2. Glare intensity and illumination for low beams, midbeams, and high beams.

Beam	Aim	Intensity (cd) at Separation Distance 2,400 Ft	1,200 Ft	600 Ft	Illumination (ft-c) at Separation Distance 2,400 Ft	1,200 Ft	600 Ft
6014 low	Nominal	–	1 483	1 066	–	0.001	0.003
6014 low	1 deg up	–	4 938	3 504	–	0.003	0.009
Mid	Nominal	–	2 242	1 633	–	0.002	0.005
Mid	1 deg up	–	6 160	4 392	–	0.004	0.012
6014 high	Nominal	63 504	59 649	51 293	0.011	0.041	0.142

Note: 1 ft-c = 10.76 lx; 1 ft = 0.3048 m; and 1 deg = 0.017 rad.

Figure 6. Simulation visibility distances for high-beam meetings.

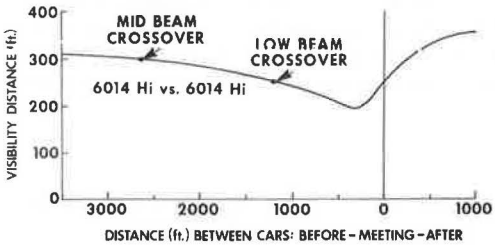

Table 3. Glare intensity and illumination as seen in the interior rearview mirror.

Beam	Aim	Intensity (cd)	Illumination (ft-c)	Ratio
6014 low	Nominal	517	0.048	1.0
6014 low	1 deg up	1 761	0.162	3.3
Mid	Nominal	1 158	0.107	2.2
Mid	1 deg up	6 809	0.627	13.1
6014 high	Nominal	18 282	1.685	35.1

Note: 1 ft-c = 10.76 lx; and 1 deg = 0.017 rad.

the opposing vehicle's head lamps are given in Table 2 for selected longitudinal separation distances between the vehicles. For example, in Table 2, at a separation distance of 1,200 ft (366 m), U.S. 6014 low beams provide a glare intensity of 1483 cd at the driver's eyes when the lamps are aimed correctly but 4938 cd when they are aimed 1 deg (0.017 rad) up. Thus, although the visibility was greater in meetings between vehicles whose low beams were aimed 1 deg (0.017 rad) up than when both were aimed to specification, the drivers were exposed to more than 3 times the glare intensities in the former case than in the latter. In meetings between vehicles equipped with correctly aimed midbeams, the glare intensity was 2242 cd at 1,200 ft (366 m), which is 51 percent greater than the glare intensity caused by low beams. However, it is less than half the intensity to which drivers are exposed when meeting a vehicle whose low beams are aimed 1 deg (0.017 rad) up. Therefore, the visibility increase provided by midbeams is obtained with considerably less increase in glare intensity compared to the same visibility increase obtained by aiming the low beams 1 deg (0.017 rad) up. The glare intensity on the driver meeting midbeams aimed up 1 deg (0.017 rad) is only 25 percent greater than meeting low beams aimed up 1 deg (0.017 rad).

Figure 6 shows the computed visibility distances of a target having a 12 percent reflectance and located at the right side of a 2-lane road in meetings between vehicles equipped with U.S. 6014 high beams. The resultant glare intensities, given in Table 2, are far greater than those from low beams or midbeams, aimed correctly or aimed 1 deg (0.017 rad) up. Because the visibility distance curves for high beams cross those for midbeams and low beams (Fig. 6), it is possible to determine the separation distance for switching from high to low beams to maintain maximum visibility. Switching from high beams to low beams should occur at about 1,200 ft (366 m) and from high beams to midbeams at 2,600 ft (792 m).

Another factor that determines switching from high beams is discomfort glare. The Hare and Hemion survey (6) indicates that dimming to low beams from high beams occurs at a mean distance of just over 1,700 ft (518 m), averaged over a number of driving conditions. However, 25 percent of the drivers dimmed their high beams at 2,400 ft (731 m) or more. At this distance, glare illumination is about 0.01 footcandles (0.1076 lx). If this is taken as a criterion for discomfort glare for conditions where the angles between the opposing car's head lamps and the driver's line of sight are small, then a 1-deg (0.017-rad) upward misaim of low beams and midbeams may cause discomfort at about 600 ft (183 m). Further, it can be inferred that high beams, whose maximum intensity is raised to 200 000 cd, will be likely to produce this level of glare illumination at about 4,000 ft (1219 m). Dimming distances for such beams are likely to be increased.

If midbeams replace low beams as meeting beams, the use of higher intensity high beams becomes reasonable because the midbeam visibility curve crosses over the high-beam curve at a separation distance of 1,400 ft (427 m). Thus, switching to midbeams can be done earlier without further loss of visibility and at lower high-beam glare levels.

Glare From Rearview Mirrors

Another major consideration in developing midbeams is the head-lamp effect on both discomfort and disability glare in rearview mirrors. Preliminary calculations show that, with a following vehicle in the same lane at a distance of 100 ft (30 m), the intensities and illumination values at the driver's eyes from a conventional interior mirror (assuming an interior mirror reflectivity of 0.85 and a rear window transmissivity of 0.88) can be high. Midbeam intensities and illumination values are about double low-beam values for nominal aim of the beam, as given in Table 3. With a 1-deg (0.017-rad) upward misaim, the low-beam values increase by a factor of about 3. Midbeam values at 1 deg (0.017 rad) are about 6 times greater than midbeam values at nominal aim and 13 times greater than low-beam values at nominal aim.

These data show that the aim of midbeams is more critical than that of low beams to avoid discomfort and disability glare to preceding drivers. Glare intensities of head lamps in rearview mirrors can readily exceed those from opposing vehicles (7).

DISCUSSION

The results of the computer simulation evaluations have shown that midbeams, in meetings with other vehicles, can provide drivers with about 20 percent greater visibility of targets on the right side of the road than do low beams. Midbeams also allow drivers to dim from high beams at greater separation distances, thereby reducing glare and simultaneously retaining better visibility. So, introducing midbeams would make it more feasible to introduce high beams of greater intensity (e.g., 200 000 cd).

Midbeams, when correctly aimed or misaligned 1 deg (0.017 rad) upward, did not increase direct glare levels substantially more than low beams. Correct alignment of midbeams must be maintained, though, particularly to control beam intensities in rearview mirrors. But, the use of low-reflectance interior and exterior mirrors will reduce this problem (8).

The studies that have been described were limited to those with targets on the right side of the lane. Although this is probably the zone of greatest importance for vehicle control and obstacle detection, the visual task becomes more difficult if the target is on the left of the lane because the disability glare effect will be greater. The visibility and glare performance of the midbeams for other target locations and for roads that have vertical and horizontal curvature must be evaluated.

There is a growing need to better understand the factors that affect discomfort glare from headlights so that modeling of this aspect can be carried out. Analytic methods used to evaluate discomfort glare from fixed luminaires may be partly applicable to the dynamic vehicle meeting case (9).

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