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HEADLAMP BEAM-PATTERN SHIFTS WITH THERMOPLASTIC COMPLEX REFLECTORS: A COMPARISON TO SHIFTS FROM OTHER CAUSES

Michael Sivak
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Michael Sivak
Michael J. Flannagan

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

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16. Abstract

Traditional headlamps use functional lenses that focus or disperse the light. Thus, the optical control of traditional headlamps is achieved, to a large extent, by the lenses. In contrast, one of the new trends in automotive headlighting eliminates the need for functional lenses by incorporating the optics in the reflectors. However, thermal effects in headlamps with such reflectors have a greater influence on the location of the beam pattern than in headlamps with conventional reflectors, especially if the complex reflector is made of a thermoplastic material. A study by Sherman et al. (1995) reported the vertical and horizontal beam-pattern shifts with thermoplastic complex reflectors to be on the order of 0.13° and 0.08°, respectively. The present study was designed to evaluate these beam-pattern shifts relative to shifts from other known causes. The analysis indicates that the shifts in the beam pattern associated with the use of thermoplastic complex reflectors of the magnitude reported by Sherman et al. (1995) will not appreciably change the current on-the-road misaim of low-beam headlamps in the United States.

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Contents

Introduction

Traditional headlamps use functional lenses that focus or disperse the light. Thus, the optical control of traditional headlamps is achieved, to a large extent, by the lenses. In contrast, one of the new trends in automotive headlighting eliminates the need for functional lenses by incorporating the optics in the reflectors. These reflectors are referred to as complex (or optics-in) reflectors.

For headlamps with complex reflectors, the development of thermal gradients in the reflectors can have a greater effect on the location of the beam than for headlamps that use functional lenses. Consequently, it is important to assess for headlamps with complex reflectors the likely amount of shift in the beam pattern associated with thermal effects, and evaluate the importance of such shifts. It is of particular importance to perform such evaluations for complex reflectors made of thermoplastic materials, because they appear to exhibit greater shifts in the beam pattern than complex reflectors made of thermoset materials.

Sherman, Ahrens, Kosmatka, Uebruesk, and Sonnenberg (1995) evaluated the shifts in beam patterns for complex reflectors made of each of two types of thermoplastic materials, an unfilled polyetherimide (PEI), and an unfilled blend of PEI and a high heat polycarbonate (HH-PC). They tested ten low-beam headlamps (five made of each material), and reported the average shifts that took place over about an hour of lamp operation. The measurement process itself was extended in time. The first measurement begun 1 minute after the lamp was turned on and it ended at 5 minutes; the second measurement was made between 60 and 64 minutes. The average vertical shift between these measurements was 0.122° for PEI, and 0.145° for HH-PC. The average horizontal shift was 0.046° for PEI, and 0.102° for HH-PC.

The present study was designed to evaluate the relative importance of the shifts in the beam pattern reported by Sherman et al. (1995). Two sets of analyses were performed. In the first set of analyses, the magnitudes of the shifts when using thermoplastic complex reflectors were compared with the known shifts due to other factors, including static and dynamic loading, in-service changes, lamp replacement without reaiming, and errors in reaiming. The second set of analyses estimated the effect of thermoplastic complex reflectors on the percentage of in-use, U.S., low-beam headlamps aimed outside of the SAE specification for misaim.

Overall Aim of Headlamps in Use

In a nationwide sample, Olson and Winkler (1985) evaluated the aim of low beams on 964 in-use vehicles. In a follow-up study, Copenhaver and Jones (1992) measured the aim of lamps on 768 vehicles from two states. Using the means and standard deviations listed in Olson and Winkler (1985) and Copenhaver and Jones (1992) (and assuming normal distributions), we calculated the amount of misaim that would be exceeded by 50% of the lamps. These calculations (and several analogous ones later in this report) derived the amount of misaim at ±0.675 standard deviations from the corresponding means. The rationale is that 25% of all cases under a normal distribution will be more extreme than the mean plus 0.675 standard deviations, and 25% will be more extreme than the mean minus 0.675 standard deviations. The results of these calculations are shown in Table 1.

Based on the findings of Olson and Winkler, and Copenhaver and Jones, we estimate that the current limits for misaim of 50% of lamps are ±0.5°, both vertically and horizontally.

Table 1. The amount of misaim that 50% of lamps (±0.675 standard deviations) would be expected to exceed.

Sample	Vertical misaim of at least*	Horizontal misaim of at least*
Olson and Winkler (1985)	-0.75°, +0.46°	-0.53°, +0.53°
Copenhaver and Jones (1992)	-0.40°, +0.47°	-0.58°, +0.17°

*If the mean of the distribution is not equal to 0, the interval will not be symmetrical around 0.

Factors Influencing Aim

Static loading

The pitch of a vehicle (and thus the vertical aim of the headlamps) is influenced by the load, whether it be passengers, cargo, or fuel. Headlamp leveling devices are designed to compensate for changes in load, but their usage in the United States is infrequent. The available data on the effect of static load on vertical aim are presented in chronological order in Tables 2 through 10.

The data in Tables 2 through 10 indicate that newer cars are generally less susceptible to changes in static load than were cars of 20 to 30 years ago, presumably because of changes in vehicle suspensions. Consequently, our conclusions will be based on recent data.

Fuel level changes. The data of Olson and Winkler (1985) for 20 vehicles indicate that the median vertical change from empty to full tank was about 0.2°. The median change obtained by Copenhaver and Jones (1992) was smaller (0.07°), but the change was measured from "typically" a quarter full to full tank. Thus, while the vehicles used in Copenhaver and Jones were newer, Olson and Winkler's measures were better documented and spanned a wider range of fuel levels. Thus, our best estimate of the median change of pitch in current vehicles, from empty to full fuel tank, is 0.2°—the value obtained by Olson and Winkler (1985).

Changes in passenger and trunk loads. Olson and Winkler (1985) found that adding the full rated load to a vehicle containing only a driver resulted in a median change in pitch of 1.1°. Copenhaver and Jones (1992) found no significant correlation between actual load on the road and the aim of headlamps. However, the lack of correlation *across vehicles* between the actual load on the road and the aim of headlamps obtained by Copenhaver and Jones (1992) cannot be taken to imply that there is not a significant relation between these two variables *within vehicles*. Consequently, our best estimate of the median effect of adding passengers and full rated load to a vehicle that contains only a driver—1.1°—is again based on the data by Olson and Winkler.

Table 2. Changes in vertical aim as a function of static loading (Chrysler, undated; cited by Hull, Hemion, and Cadena, 1972).

Condition	Median	Minimum	Maximum
From empty to 5 passengers and full fuel tank (11 vehicles)	0.94°	0.72°	1.01°
From empty to full rated load (11 vehicles)	1.50°	1.42°	1.65°

Table 3. Changes in vertical aim as a function of static loading (Horning, undated; cited by Hull et al. 1972).

Condition	Median	Minimum	Maximum
From empty to 156 lbs driver and 206 lbs trunk load (12 vehicles)	0.78°	-0.09°	1.09°
From empty to 156 lbs driver, 156 lbs front passenger, and 206 lbs trunk load (12 vehicles)	0.79°	0.01°	1.23°
From empty to 156 lbs driver, 156 lbs front passenger, 456 lbs rear passengers, and 206 lbs trunk load (5 vehicles)	1.01°	0.10°	1.35°
From empty to 156 lbs driver, 306 lbs front passengers, 456 lbs rear passengers, and 206 lbs trunk load (6 vehicles)	1.41°	1.34°	1.66°

Table 4. Changes in vertical aim as a function of static loading (Hignett, 1970).

Condition	Median	Minimum	Maximum
From as actually loaded when drivers volunteered for the study to empty and fuel tanks half full (392 vehicles)	0.25° — 0.5°	-0.75° — -1°	1.5° — 1.75°

Table 5. Changes in vertical aim as a function of static loading (Walker, 1972).

Condition	Median	Minimum	Maximum
From empty and no gas to full gas tank, driver, and one front passenger (2 vehicles)	0.38°	0.36°	0.40°

Table 6. Changes in vertical aim as a function of static loading (Olson and Mortimer, 1973).

Condition	Median	Minimum	Maximum
From 150 lbs driver and full gas to empty with no gas (5 vehicles)	-0.29°	-0.63°	0.48°
From 150 lbs driver and full gas to full passenger load (7 vehicles)	0.25°	0.06°	0.63°
From 150 lbs driver and full gas to full rated load (7 vehicles)	1.01°	0.29°	1.24°
From 150 lbs driver and full gas to 150 lbs front and full trunk load (7 vehicles)	0.67°	-0.10°	1.30°

Table 7. Vertical aim as a function of static loading (Sator, 1984).

Condition	Median	Minimum	Maximum
From empty to 60 kg on each seat and luggage to maximum axle load (13 vehicles)	1.80°	1.00°	2.63°
From empty to 60 kg on the driver's seat and luggage to maximum axle load (11 vehicles)	2.41°	1.51°	3.41°

Table 8. Vertical aim as a function of static loading (Olson and Winkler, 1985).

Condition	Median	5th percentile	95th percentile
Empty to full tank (20 vehicles)	0.2°	0.0°	0.4°
Driver only to full rated load (20 vehicles)	1.1°	0.6°	1.5°
Driver only to full passenger load (20 vehicles)	0.7°	-0.1°	1.0°
Driver only to driver plus one front passenger (20 vehicles).	0.0°	-0.1°	0.1°
Driver only to additional 100 lbs in trunk (20 vehicles)	0.3°	0.1°	0.5°
Driver only to full trunk (20 vehicles)	1.0°	0.5°	1.3°

Tables 9. Changes in vertical aim as a function of static loading (Copenhaver and Jones, 1992).

Condition	Median	Minimum	Maximum
From "typically" less than a quarter tank of fuel to full tank (15 vehicles)	0.05°	0°	0.19°

Tables 10. Relationship between vehicle load and headlamp aim (Copenhaver and Jones, 1992).

Condition	Result
Correlation between vehicle load and headlamp aim (768 vehicles)	Not statistically significant

Dynamic loading

Aerodynamic forces during steady-speed driving. Information on the effect of aerodynamic forces on the pitch of a vehicle are presented in Tables 11 through 13. Tables 11 and 12 show empirical data obtained by Hull et al. (1972) and Huculak (1978), while those in Table 13 are calculated values derived by Olson and Winkler (1985). Based on the calculations by Olson and Winkler (1985), and the fact that, if anything, dynamic loading has decreased further since 1985 because of continuing improvements in aerodynamic design, the typical aerodynamic changes currently do not exceed 0.1°.

Table 11. Changes in vertical aim as a function of aerodynamic forces (Hull et al., 1972).

Condition	Median	Minimum	Maximum
From 0 to 80 mph (3 vehicles)	0.5°	0.2°	0.5°

Table 12. Changes in vertical aim as a function of aerodynamic forces (Huculak, 1978).

Condition	"Result"
From 0 to 50 mph (number of vehicles not specified)	0.25°

Table 13. Changes in vertical aim as a function of aerodynamic forces (Olson and Winkler, 1985).

Condition	Median	Minimum	Maximum
From 0 to 55 mph (22 vehicles)	+0.04°	-0.13°	+0.33°
From 0 to 55 mph, 10 mph head wind (22 vehicles)	+0.06°	-0.18°	+0.46°
From 0 to 55 mph, 30 mph head wind (22 vehicles)	+0.09°	-0.23°	+0.61°
From 0 to 55 mph, 10 mph side wind (22 vehicles)	+0.06°	-0.13°	+0.50°
From 0 to 55 mph, 30 mph side wind (14 vehicles)	+0.08°	-0.14°	+0.74°

Acceleration/deceleration. The data of Hull et al. (1972) are summarized in Table 14. More recent data of Ishikawa and Kobayashi (1993) and Toop (1993) are summarized in Tables 15 and 16. Based on the two latter studies, we conclude that vertical aim during acceleration and deceleration can change by at least 1° and 0.7°, respectively.

Tables 14. Changes in vertical aim as a function of acceleration and deceleration (Hull et al., 1972).

Condition	Median	Minimum	Maximum
From 0 g to a median of 0.36 g (a range 0.3 g to 0.56 g) (7 vehicles)	1.0°	0.9°	1.2°
From 0 g to a median of -0.9 g (a range -0.8 g to -0.9 g) (7 vehicles)	-2.1°	-1.8°	-2.7°

Tables 15. Changes in vertical aim as a function of acceleration and deceleration (Ishikawa and Kobayashi, 1993).

Condition	Peak change
Acceleration from 0 to 45 km/h (1 vehicle; g forces not specified)	+1.0°
Deceleration from 45 to 0 km/h (1 vehicle; g forces not specified))	-0.7°

Tables 16. Changes in vertical aim as a function of acceleration and deceleration (Toop, 1993).

Condition	Peak change
Acceleration from 0 to 105 km/h (1 vehicle; g forces not specified)	+1.6°
Deceleration from 105 to 0 km/h (1 vehicle; g forces not specified))	-0.8°

In-service change within headlamps

The only available data are those of Hull et al. (1972) on changes in the location of the highest intensity for sealed beams after 20 to 65 hours of service. The data provided by Hull et al. are summarized in Table 17.

In-service changes in headlamp/vehicle system

No recent data were available. The data from Hull et al. (1972) for sealed beams are summarized in Table 18.

Table 17. Changes in the location of the highest intensity after 20 to 65 hours of in service (Hull et al., 1972).

Measure	Mean	Maximum
Change (6 lamps)	"less than 0.5°"	1°

Table 18. Changes in aim after 828 to 6,463 miles (Hull et al., 1972).

Measure	Mean	Maximum
Vertical change (27 vehicles)	0.04°	1.24°
Horizontal change (27 vehicles)	0.01°	0.57°

Lamp replacement without reaiming

Sealed beams. Table 19 presents data from Olson (1982) on changes in aim for sealed-beam lamps when they were replaced without reaiming. Using the standard deviations of these data, we can calculate how much misalignment there would be for a certain proportion of lamps. Such calculations show that 50% of sealed-beam lamps will be misaimed by at least the amount shown in Table 20.

Table 19. Estimated standard deviation of aim of sealed-beam headlamps after replacement without reaiming (Olson, 1982).

Measure	Standard deviation
Vertical aim (36 headlamps)	0.30°
Horizontal aim (36 headlamps)	0.44°

Table 20. The amount of misaim that 50% of sealed-beam headlamps (±0.675 standard deviations) would be expected to exceed after replacement without reaiming (based on the data from Olson, 1982).

Vertical misaim of at least	Horizontal misaim of at least
-0.20°, +0.20°	-0.30°, +0.30°

Replaceable bulbs. The use of sealed-beam headlamps in the United States is continuously decreasing. Thus, of more relevance to the current and future situation in the United States is the effect of bulb replacement on aim in headlamps with replaceable bulbs. Although we do not know of any published data on U.S.-type replaceable bulbs, Brown, Charlesworth, and Pinkney (1983) present data on the changes in aim with replacement of European H4 bulbs (see Table 21). Using the standard deviations derived by Brown et al. (1983), we can calculate how much misalignment there would be for a certain proportion of lamps. Such calculations show that 50% of lamps will be misaimed by at least the amount shown in Table 22.

Table 21. Estimated standard deviation of aim of headlamps with replaceable bulbs after replacement without reaiming (Brown et al., 1983).

Measure	Standard deviation
Vertical aim	0.15°
Horizontal aim	0.64°

Table 22. The amount of misaim that 50% of headlamps with replaceable bulbs (±0.675 standard deviations) would be expected to exceed after replacement without reaiming (based on the data from Brown et al., 1983).

Vertical misaim of at least	Horizontal misaim of at least
-0.10°, +0.10°	-0.43°, +0.43°

Errors in reaiming

Olson and Mortimer (1974) estimated standard deviations of aims associated with different aiming techniques. The estimates were based on pooling estimated variances due to several pertinent factors. These factors included "dog tracking" (the drive axle not being perpendicular to the longitudinal axis of the vehicle), longitudinal axis misalignment, variability of the aimer (if relevant), etc. Thus, these estimates include not only the variances due to the aiming techniques themselves, but attempt to also include variances for factors that the aiming techniques cannot control. The results of Olson and Mortimer's calculations (for U.S. low beams) are shown in Table 23. Their estimated total standard deviation for vertical visual aiming with a screen (0.35°), compares well with the between-subject standard deviation for U.S. low beams for the process of visual aiming itself (0.22°) obtained by Sivak, Flannagan, Chandra, and Gellatly (1992).

Using the standard deviation derived by Olson and Mortimer (1974), we can calculate how misaimed a certain proportion of lamps would be when they are nominally aimed. Such calculations show that 50% of nominally aimed lamps would be actually misaimed by at least the amount shown in Table 24.

Table 23. Estimated standard deviation of aims by different aiming techniques (Olson and Mortimer, 1974).

Technique	Standard deviation of vertical aim	Standard deviation of horizontal aim
Visual aiming with a screen	0.35°	0.55°
Photometric aiming	0.34°	0.50°
Mechanical aiming	0.36°	0.42°

Table 24. The amount of misaim that 50% of lamps (±0.675 standard deviations) would be expected to exceed after they are nominally aimed by different aiming techniques (based on standard deviations calculated by Olson and Mortimer, 1974).

Technique	Vertical misaim of at least	Horizontal misaim of at least
Visual aiming with a screen	0.24°	0.37°
Photometric aiming	0.23°	0.34°
Mechanical aiming	0.24°	0.28°

Summary

The previous sections reviewed the magnitude of misaim due to several factors, in relation to shifts from the use of thermoplastic complex reflectors. Several of the older reviewed studies are not directly relevant to the current situation. The studies that, in our opinion, are relevant to the current situation in the United States are summarized in Table 25. The information in Table 25 indicates that shifts of the magnitude reported by Sherman et al. for the effects of thermoplastic complex reflectors are small relative to misaim from other causes. The next section will provide an estimate of the effects of thermoplastic complex reflectors on in-use aim of low beams in the United States.

Table 25. Summary of the relevant reviewed studies.

Measure	Finding	Source(s)
Vertical misaim that is exceeded by 50% of on-the-road lamps	±0.5°	Olson and Winkler (1985); Copenhaver and Jones (1992)
Horizontal misaim that is exceeded by 50% of on-the-road lamps	±0.5°	Olson and Winkler (1985); Copenhaver and Jones (1992)
Change in vertical aim from empty to full fuel tank	+0.2°	Olson and Winkler (1985)
Change in vertical aim from driver to full rated load	+1.1°	Olson and Winkler (1985)
Changes in vertical aim because of aerodynamic forces during steady speeds	<0.1°	Olson and Winkler (1985)
Peak changes in vertical aim because of acceleration	>1.0°	Ishikawa and Kobayashi (1993); Toop (1993)
Peak changes in vertical aim because of deceleration	>0.7°	Ishikawa and Kobayashi (1993); Toop (1993)
Vertical misaim exceeded by 50% of lamps with replaceable bulbs without reaiming	±0.1°	Brown et al. (1983)
Horizontal misaim exceeded by 50% of lamps with replaceable bulbs without reaiming	±0.4°	Brown et al. (1983)
Vertical misaim exceeded by 50% of lamps after being "correctly" aimed	±0.2°	Olson & Mortimer (1973)
Horizontal misaim exceeded by 50% of lamps after being "correctly" aimed	±0.3°	Olson and Mortimer (1973)
Mean vertical shift for complex reflectors made from thermoplastic materials	0.12° - 0.14°	Sherman et al. (1995)
Mean horizontal shift for complex reflectors made from thermoplastic materials	0.05° - 0.10°	Sherman et al. (1995)

Vertical Misaim with Thermoplastic Complex Reflectors

Approach

The nationwide survey by Olson and Winkler (1985) that was discussed above can be used to provide an estimate of the effect of thermal changes in thermoplastic complex reflectors on in-use aim of low beams in the United States. This is a conservative estimate (the current variability is greater than that obtained by Olson and Winkler), because Olson and Winkler's data do not take into account dynamic loading and fuel-level effects (most of their data were taken after refueling at a service station). What they do take into account is static loading (the data were collected with all passengers and baggage in place) and misaim due to replacement of replaceable bulbs without reaiming. Although there must have been very few replaceable bulbs in Olson and Winkler's sample (in the United States they were first allowed in 1983), the standard deviation of vertical aims obtained by Brown et al. (1983) after replacement without reaiming for lamps with replaceable bulbs (0.15°) is comparable to that found by Olson (1982) for sealed beams (0.2°).

The approach is illustrated in Figure 1. Using thermoplastic complex reflectors would shift the mean, and possibly enlarge the standard deviation, of the current distribution of misaims. The question of interest is how many headlamps would exceed a certain amount of misaim. The limits of misaim that we used are the current SAE specification—4 inches at 25 feet, or ±0.764° (SAE, 1981).

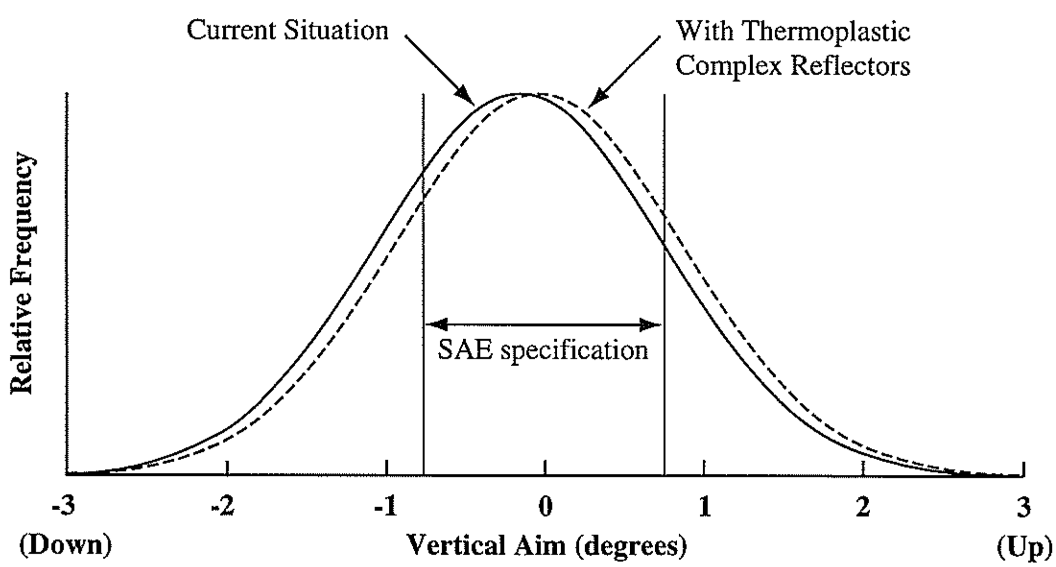

Figure 1. An illustration of the approach used to evaluate the effect of vertical shift in aim due to the use of thermoplastic complex reflectors.

Lamps without thermoplastic reflectors

Olson and Winkler (1985) provide means and standard deviations separately for the driver and passenger side. The mean vertical aim was -0.12° on the driver side and -0.17° on the passenger side. The standard deviations were 0.90° for both sets of lamps. Thus, we used -0.145° as our estimate of the population mean (the mean of -0.12° and -0.17°), and 0.90° as our estimate of the population standard deviation. Using these parameters, and assuming a normal distribution, we calculated the percentage of lamps within ±0.764° (Table 26, line 1). (These percentages are not identical to those actually obtained by Olson and Winkler, because their sample was not completely normal.)

Lamps with thermoplastic reflectors

We obtained the raw data (Sherman, 1995) that formed the basis for the means reported in Sherman et al. (1995). Using the raw data, we calculated the standard deviations of the shifts due to the use of thermoplastic complex reflectors (Table 26, lines 2 and 3). (The means were reported in Sherman et al., 1995.) Assuming additivity of the variances of the data from Olson and Winkler and those from Sherman et al., we calculated a predicted variance for lamps that would use thermoplastic complex reflectors, but would be otherwise identical to those surveyed by Olson and Winkler. The means of the distributions with thermoplastic complex reflectors were derived by adding the mean shifts obtained by Sherman et al. to the mean from Olson and Winkler. The resulting means and standard deviations are listed in Table 26 (lines 4 and 5). Because the variability of the shifts reported by Sherman is small relative to the variability in aims reported by Olson and Winkler, the standard deviations are virtually unchanged.

Table 26. Estimated parameters for distributions of vertical aim, and shifts in aim, without and with thermoplastic complex reflectors.

Distribution	Source	Mean	Standard deviation
Aim without thermoplastic complex reflectors	Olson & Winkler (1985)	-0.145°	0.900°
Shift from without to with PIE thermoplastic complex reflectors	Sherman et al. (1995) Sherman (1995)	0.122°	0.050°
Shift from without to with HH-PC thermoplastic complex reflectors	Sherman et al. (1995) Sherman (1995)	0.145°	0.006°
Aim with PIE thermoplastic complex reflectors	Calculated	-0.023°	0.900°
Aim with HH-PC thermoplastic complex reflectors	Calculated	0.000°	0.901°

Percentage of lamps exceeding the SAE specification for misaim

Using the parameters from Table 26, we calculated the percentages of lamps exceeding SAE specification. The results of these calculations (see Table 27) indicate the following concerning the use of thermoplastic complex reflectors. First, the percentage of lamps aimed lower than the lower bound of the SAE specification would *decrease* by about 4.4% (the average of 4.1 and 4.8). Second, the percentage of lamps aimed higher than the upper bound of the SAE specification would *increase* by about 3.8% (the average of 3.5 and 4.2). Third, the total percentage of lamps misaimed outside of the current SAE specification would remain approximately the same.

The results given in Table 27 are also shown in Figure 1 on page 14. The solid line in Figure 1, labeled "Current Situation," represents the distribution treated in the first line of Table 27. Although the shifts for PIE and HH-PC reflectors are slightly different, they are similar enough that the dashed line in Figure 1 represents either case within the limits of precision to which the figure is drawn.

Table 27. Percentage of lamps exceeding the SAE specification for misaim (±0.764°) for distributions without and with thermoplastic complex reflectors.

Distribution	Percentage of lamps aimed lower than -0.764°	Percentage of lamps aimed higher than +0.764°	Percentage of lamps aimed outside of ±0.764°
Current situation, without thermoplastic complex reflectors	24.6	15.6	40.2
With PIE thermoplastic complex reflectors	20.5	19.1	39.6
With HH-PC thermoplastic complex reflectors	19.8	19.8	39.6
Change due to PIE thermoplastic complex reflector	-4.1	+3.5	-0.6
Change due to HH-PC thermoplastic complex reflector	-4.8	+4.2	-0.6
Average change due to PIE and HH-PC thermoplastic complex reflectors	-4.4	+3.8	-0.6

Horizontal Misaim with Thermoplastic Complex Reflectors

Sherman et al. (1995) reported that the horizontal shifts associated with the use of PIE and HH-PC thermoplastic materials were smaller than the corresponding vertical shifts (0.046° and 0.103° versus 0.122° and 0.145°). Consequently, it is reasonable to conclude (without an analysis analogous to that performed for vertical misaim in Tables 26 and 27) that the amount of horizontal shift reported by Sherman et al. is unlikely to substantially affect the in-use horizontal aim of U.S. low beams. In addition, the practical consequences of horizontal misaim are less important than those of vertical misaim (Sivak, Flannagan, and Sato, 1994b). This is because horizontal gradients of U.S. low beams are more gradual than vertical gradients (Sivak, Flannagan, and Sato, 1994a).

Conclusions

Vertical shifts associated with thermoplastic complex reflectors

Based on the information in Tables 25 and 27, it is our conclusion that the vertical shifts in the low-beam pattern associated with the use of thermoplastic complex reflectors of the magnitude reported by Sherman et al. (1995) will not appreciably change the current on-the-road misaim of lamps in the United States. Because the vertical shifts reported by Sherman et al. (1995) were upward, there will be a small increase in the percentage of lamps misaimed outside of the upper limit of the current SAE specification. Thus, the use of thermoplastic complex reflectors would slightly increase the glare values of U.S. low-beam headlamps. However, this slight increase in lamps misaimed up would be offset by a decrease in the percentage of lamps misaimed too low. Consequently, assuming there is no change in aiming methods, the use of thermoplastic complex reflectors would slightly increase the visibility provided by U.S. low-beam headlamps.

Horizontal shifts associated with thermoplastic complex reflectors

Horizontal misaim of U.S. lamps is less important than vertical misaim, because horizontal gradients are more gradual than the corresponding vertical gradients. Furthermore, Sherman et al. (1995) reported that the horizontal shifts were smaller than the vertical shifts. These facts lead us to conclude that horizontal shifts in the beam pattern associated with the use of thermoplastic complex reflectors of the magnitude reported by Sherman et al. (1995) are not of practical consequence for U.S. low-beam headlamps.

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