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Recommendations of the SAE Task Force on Headlamp Mounting Height

RATIONALE

The technical report covers technology, products, or processes which are mature and not likely to change in the foreseeable future.

STABILIZED NOTICE

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1. SCOPE

The SAE International task force on headlamp mounting height has considered the ramifications of reducing the maximum mounting height of headlamps on highway vehicles. The task force has concluded that it is in the best interest of the driving public to make a substantial reduction in the recommended maximum height at which headlamps, particularly low-beam headlamps, may be mounted. Heights as low as 36 to 40 in (90 to 100 cm) have been considered. New tractor vehicles are in fact being designed with headlamps mounted in this range. Further recommendations were withheld in anticipation of tests to demonstrate the effect of mounting height on the legibility of certain overhead signs.

1.1 Background

For the past several years there has been increasing concern on the part of automotive lighting committees within SAE and automotive lighting regulators at National Highway Traffic Safety Administration (NHTSA) over the glare from vehicle headlamps. Complaints to NHTSA from users indicate that both mirror glare and glare from opposing vehicles contribute to the problem.

Present mounting height standards allow headlamps to be mounted up to a height of 54 in (from the ground plane to the center of the headlamp). Generally, passenger vehicle occupants are seated such that their eye level ranges from about 40 in to 45 in. (100 to 114 cm). By comparing the range of vehicle driver’s drivers' eyes and mirrors with the range of headlamp heights, it can be shown that passenger vehicle drivers' eyes and the vehicle’s rearview mirrors can be located below the top cutoff of the projected beam of a following vehicle. In this high gradient zone, the light intensity from a lower beam headlamp beam, located 40 ft behind a driver's rearview mirror, will increase at least 20% (40% in some lamps) for every 1/10 degree (0.84 in) below the top cutoff of the beam pattern.

For a rearview mirror located 5 in below the top cutoff of a headlamp beam pattern, the beam gradients of 20 to 30% per 1/10 degree would cause an increase of 300% to 500% of the light that a driver would experience if the mirror were located exactly at the top cutoff. A 1000% increase in eye illumination could be experienced in comparison to that from a mirror located at an approximately equal distance above the top cutoff. These numbers give us a clue as to why passenger vehicle drivers are noticing the differences in glare from high-mounted headlamps.

1.2 History

The conflict between where passenger car drivers are located and where vehicle headlamps can be mounted can be traced by reviewing historical trends in vehicle lighting.

Passenger vehicle sizes and heights are decreasing as many vehicles are being downsized and as a result, the elevation of drivers' eyes and rearview mirrors has been reduced accordingly. Light trucks (pickups, vans, minivans and sport utility vehicles) on the other hand, are not decreasing in either size or market share. With headlamps routinely mounted well above those on passenger cars, light trucks are more popular than ever. The higher mounting heights on these vehicles most likely represent a substantial part of the increase in complaints about headlamp glare.

When headlamp mounting height standards were first written, headlamps on passenger vehicles were routinely mounted at 30 or even 32 in (approximately 79 cm) above the ground plane, 8 to 10 in above the 22 to 24 in (approximately 58 cm) mounting height we see today. It is probably safe to assume that the eyepoint of the driver was also higher by 8 to 10 in. If we use 44 in (112 cm) for today's passenger car driver, a rearview mirror mounted 2 or 3 in (6.4 cm) above the driver's eye in the old standard-setting vehicles would have an elevation of 54 to 57 in (44 + 8 + 2 to 44 + 10 + 3 in), approximately 141 cm. This is essentially identical with the maximum mounting height of the headlamp that was prescribed at that time.

Another reason for the recent trend of dissatisfaction and irritation with vehicle lighting among passenger vehicle drivers may be found in the headlamp beam intensity distribution itself. In one of the first SAE photometric standards, J579a, the required light level was only about 75% of the present standard and only 60% of more advanced standards in Federal Code 49 CFR Part 571.108. In fact, contemporary halogen headlamps generally achieve 100% more light at the 1/2-degree-down seeing point than was available from the brightest of the SAE J579a design headlamps. At the time the mounting height standard was defined, a driver would have been exposed to roughly about 2800 cd viewing a following vehicle's 54 in mounting height headlamps (designed to SAE J579a) in his rearview mirror.

Today rearview mirrors (front surface, prism) in their "night" position may reflect as little as 4% of the incident light. In spite of their elevation in the headlamp beam, the glare concern for rearview mirrors is low compared to driver's side view mirrors. A side view mirror (no "night" adjustment; 50% reflectance), mounted at about 40 in or less, could theoretically be over 1.6 degrees below the horizontal of a headlamp mounted at 54 in / 137 cm. At a distance of 40 ft (12.2 m) on some halogen headlamps using axial-filament light sources, this is the approximate location of the maximum beam intensity (MBI). MBIs of over 30 000 cd are possible. This represents more than a tenfold increase of the exposure intensity over that which was typical when the standard was formulated.

It is apparent that mounting height or aiming guidelines must be revised to accommodate the changes in aerodynamic vehicle styling and headlighting technology. The most technically defensible solution is to lower the current maximum mounting height for headlamps in order to reduce the maximum exposure level to a reasonable value.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein.

2.1.1 Sivak, M., Flannagan, M., Gellatly, A.W., "Influence of Truck Driver Eye Position on Effectiveness of Retroreflective Traffic Signs," Ltg. Res. Technology, 25(1) 31-36, (1993)

2.1.2 Cobb, J., "Roadside Survey of Vehicle Lighting 1989," Transport and Road Research Laboratory, U.K., Research Report 290, (1989)

2.1.3 Kosmatka, W.J., "Obstacle Detection with Headlamps: Threshold Luminance or Contrast," Proceedings of IES, IENSA Conference - 1995, (1995)

2.1.4 Kosmatka, W.J., "Obstacle Detection Rationale for Vehicle Headlamps," J of the IES, Winter 1995, 36-40, (1994)

3. REVELANT ISSUES IN LOWERING RECOMMENDED HEADLAMP MOUNTING HEIGHTS

It is certain that the greatest effect of such recommendations would be felt in the truck, tractor-trailer and pickup vehicle manufacturing industries. Passenger vehicles, with few exceptions, already have their headlamps mounted in the range of 22 to 26 in (56 to 66 cm). The body contours and bumper location preclude higher mounting in most passenger vehicles; vans are the notable exception. With this background one can understand why most of the following discussion centers on truck types of vehicles.

Two issues are frequently raised on the subject of lowering the mounting height of headlamps:

a. The resulting increase in the vertical separation between the driver's eyepoint and the headlamp light source on large trucks will decrease the conspicuity and legibility of retroreflective traffic control devices and highway information signs which are illuminated solely by the vehicle headlamps.

b. There will be a reduction in the visibility distance of the operator and this will reduce the chances of stopping the tractor-trailer or truck vehicle within the obstacle detection distance.

4. UNLIT TRAFFIC CONTROL DEVICES

Luminance of retroreflective overhead highway information signs (which are illuminated only by vehicle headlamps) will be reduced by virtue of the increased observation angle. The observation angle is the angle formed by a line between the driver's eye and the sign, and another line between the light source and the sign. As the driver's eye position moves upward, away from the headlamp, or as the headlamp height is lowered, the observation angle increases. For retroreflective materials, the level of light returned to an observer is reduced as the observation angle is increased. The implications of separation distances are discussed by Sivak, Flannagan and Gellatly (see 2.1.1).

Without a doubt, a loss of legibility of the sign information is undesirable. But this reasoning may be overly simplistic in the assumptions that it makes. It implies that a driver cannot take measures to compensate for the loss of visual information. Moreover, the argument ignores precedent. Some vehicles being driven on highways today already have extreme observation angles with no documented ill effects.

In order for the driver to suffer the loss of sign legibility as the direct result of headlamp location, the headlamps on his own vehicle must be the only source of illumination on the sign. On heavily traveled highways where lower beams are generally required, sign illumination is frequently the result of illumination by multiple sources, each having its own particular intensity and observation angle for the drivers in the immediate vicinity. A loss of 20 or 30% of sign luminance from one vehicle may not even be noticeable, let alone constitute a safety issue under these conditions.

In low traffic situations, a single vehicle's headlamps are sometimes the only source of sign illumination. If the operator needs the sign only as a reminder of a predetermined route or direction, then it is difficult to argue the safety implications of reduced sign legibility. Assuming that the vehicle operator really does need the information presented to make a decision, the driver is still able to exert control over the time available to view a sign. In this situation vehicle operators are able, at their option, to control the time available to formulate a decision by a reduction in the vehicle's speed. If the roadway traffic is light as postulated, then a reduction in speed, a lane change, or a momentary switch to high beam are all possible.

A comparison of truck headlamp mounting heights and vertical separation of the driver’s eyes from the headlamps is depicted in Figure 1. This is a compilation of recent data provided by truck and tractor vehicle manufacturers. The parameter of the driver's eye height is noted also. The chart makes several important points:

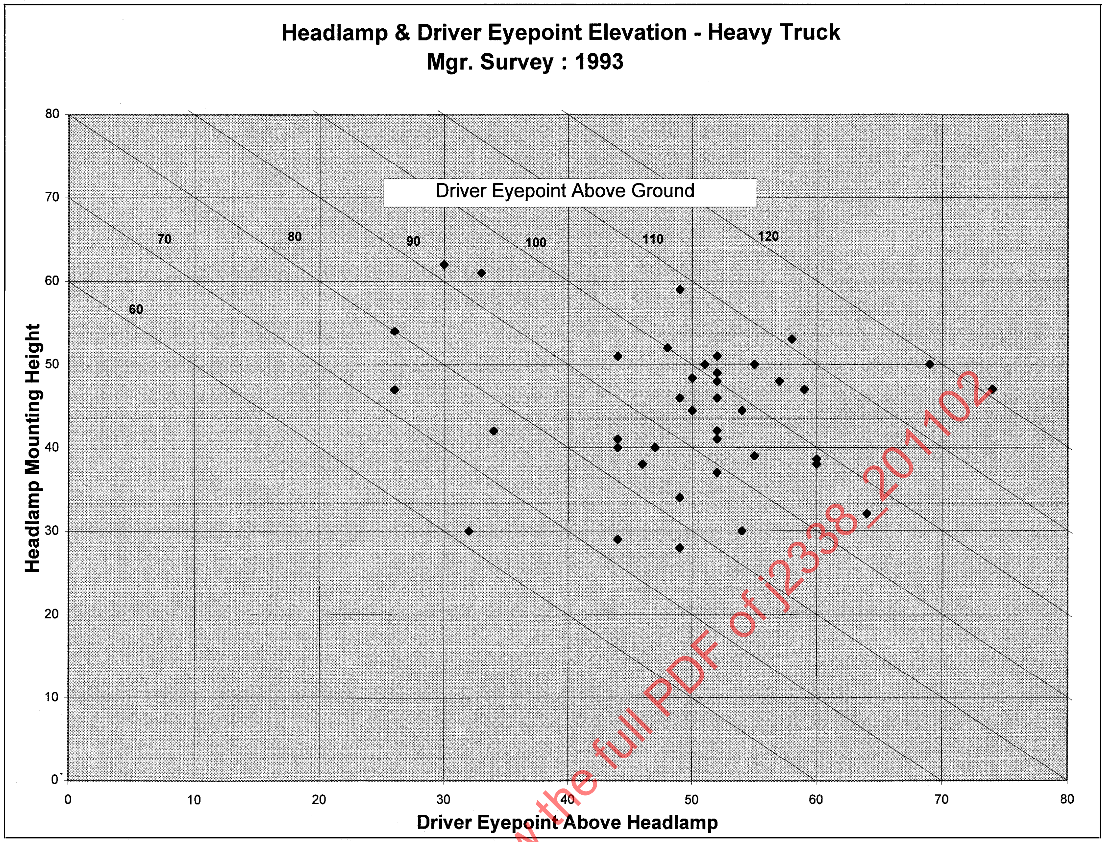

FIGURE 1 - HEADLAMP AND DRIVER EYEPOINT ELEVATION - HEAVY TRUCK
MGR. SURVEY: 1993

a. The average (or median) mounting height of a headlamp is about 45 in (114 cm).

b. There are situations where a relatively great separation between the driver's eyes and the light source (e.g., the observation angle) already exists. There are several instances in which the location of the driver's eyepoint is above the headlamp by 60 to 70 in (152 to 178 cm).

c. There are trucks on the road with headlamps mounted at 40 in (102 cm) or lower.

A study of vehicle lighting (see 2.1.2) also shows that there are many European trucks with headlamps mounted at 90 cm (36 in) and below. Interpolation of Cobb's data would indicate that the vast majority of articulated vehicles measured had headlamps mounted below the 90 cm height.

Based on these data, and having no information that the vehicles noted above have caused drivers to experience problems with large observation angles, the argument that a loss of sign legibility will have dramatic negative safety effects does not appear to be substantiated. Drivers viewing oncoming traffic from elevated positions actually experience a substantial reduction in glare and therefore their eyes remain more consistently dark-adapted.

5. DETECTION DISTANCE EFFECT

The detection or discernibility distance for headlighting systems has been studied in real roadway situations and with mathematical algorithms over the years. In almost all cases these studies concentrated on passenger vehicles. In most of these cases mounting height was not the issue.

In the limited situations in which headlamp mounting location was studied, there was a detection distance loss noted as a result of lowered mounting height of the vehicle headlamps. While numbers such as "10 ft loss per inch mounting height reduction" are stated, this was for passenger vehicle headlamps which were already mounted relatively low; in the range of 25 in (64 cm). The obstacles in some detection distance tests conducted by Roper or Meese, were 40 cm x 40 cm (16 in^2) targets. The "targets" were generally detected at 200 to 250 ft (61 to 76 m) depending on the headlamp system. The center of the target (at 8 in / 20 cm above the roadway) is located 17 in (43 cm) below the center of the headlamp at a distance of 225 ft (69 m). At this point in the beam, it is illuminated by light at about 0.36 degree below the top of the beam cutoff. This is in the area where the beam gradient is very large. A reduction of 2 in (5 cm) in mounting height implies that the location of the target center would now be located slightly over 0.04 degree higher in the beam pattern. Beam gradients in this area are generally 25%, or even 35% per 1/10 degree, and a change of one-half of 1/10 degree would imply that 12 to 16% less light illuminates the obstacle

Application of the inverse distance law would dictate that if the headlamps are lowered 2 in, the detection distance should fall by approximately 6 to 8% of 225 ft or 14 to 18 ft (4.3 to 5.5 m). So for a 1-in (2.5 cm) mounting height change, a loss of 7 to 9 ft (2.1 to 2.7 m) is implied. This analysis confirms (approximately) the generalization of 10 ft detection loss per inch mounting height reduction (about 1.2 m shorter detection distance per cm mounting height reduction). This applies, in a general sense at least, to passenger vehicles. We will see in the following sections that the rule is not generally applicable to headlamps mounted at greater mounting heights in large truck types of vehicles.

5.1 Detection Distance With Lowered Mounting Height

It is possible to determine the effect of mounting height differences by actual dynamic testing similar to that described above. However, this would be difficult and costly to do with actual trucks and tractors.

The implications of performing static testing using mock-ups of vehicle front ends, stationary targets, and driver-observers at varying heights has been discussed. Even this task was daunting for the amount and relevance of the information which might be gained. There are some who feel that static obstacle detection tests do not fairly depict actual roadway obstacle detection distances. Some of the reasons for this are the absence of secondary tasks such as lane-keeping and speed maintenance, as well as longer (or artificial) target acquisition time intervals. For these reasons, the data acquired from static tests are always somewhat insensitive to subtle light level differences. Longer detection distances—sometimes substantially longer—are typical of static tests relative to distances found in dynamic tests.

5.2 Detection Distance Model

In the interest of defining the effect of lowered mounting height without incurring the expense and time penalty of dynamic road tests, a simpler modeling experiment was undertaken. The distance at which a roadway obstacle would be discerned by the driver of a motor vehicle is a function of the obstacle luminance and contrast with the background. For many roadway situations, the background is the distant roadway surface and therefore it is at a significantly lower luminance than the illuminated obstacle. The contrast requirement is generally satisfied in this situation. At any rate over a short distance the contrast ratio can be shown to be relatively invariant and we can infer that the detection distance becomes simply a function of threshold luminance.

A model (see 2.1.3) which compares the distance-related headlamp illumination with the distance-related illumination required for detection of the obstacle was used to predict the (relative) effect of reducing headlamp height from the average noted previously (45 in / 114 cm) to a reduced (36 in / 91 cm) height. The obstacle characteristics selected for the calculations were: 3 ft^2 area (0.28 m^2), 1.5 ft (46 cm) high, 0.10 reflectance (0.1 ft-lambert/Fc). The vehicle headlamp spacing used was 60 in (1.52 m). An H6054 (Type 2B1) sealed-beam headlamp was chosen for the experiment because of its widespread use in the industry and its known level of photometric performance.

In order to determine the illumination of the obstacle at various distances from the vehicle, the angular position of the obstacle's center was calculated as a function of distance for each headlamp at the two mounting heights of interest. A representative GE H6054 headlamp was evaluated at each of these angular displacements. A programmable LMT G-1200 goniophotometer was used to make the photometric readings with the lamp aimed photometrically to its nominal fractional balance aim. The light falling on the obstacle center is the simple summation of the separate contributions of the right and left headlamps. Use of the inverse-square relationship then yields the obstacle illumination as a function of distance from the headlamps to the obstacle.

The detection requirements as a function of distance were calculated by the algorithms proposed by Kosmatka (see 2.1.4). This was done for each of two cases: one in which the driver is nonexpectant, i.e., not reasonably anticipating a roadway obstacle, and one in which the driver is expectant and has reason to anticipate that there will be an obstacle in or near the path of the vehicle.

5.3 Detection Distance Model Results

Comparison of the illumination provided by the headlamp system and the illumination required for detection or discernibility of the obstacle yielded the approximate distance at which the detection criterion is satisfied. This is shown in Table 1:

TABLE 1 - DETECTION DISTANCE

Mounting Height	Expectant Driver	Nonexpectant Driver
at 45 in (114 cm)	264 ft (80 m)	157 ft (47.5 m)
at 36 in (91 cm)	251 ft (76 m)	144 ft (43.6 m)
% change	5%	8%

5.4 Discussion of Detection Distance Results

The detection distance loss predicted by the detection distance model contradicts conventional lore based on previous studies of the distance lost per inch of mounting height reduction. There are several reasons for this. As discussed previously, the "10 ft/in rule" may take some license in rounding numbers that are somewhat less than 10 ft.

However, there is another more profound reason that we find less of a reduction at severely elevated mounting heights. It is an artifact of the beam patterns made by halogen lamps. In general, halogen type lamps have smaller, more compact coils than did their standard incandescent counterparts. The wire temperature is (generally) elevated, resulting in more lumens per watt. Also, as a general rule, the filament wire's diameter is smaller. This increases the resistance-per-unit-length and results in a shorter wire segment for a given wattage and life rating. The coiled filament is smaller in length and diameter in halogen headlamps.

The combination of more lumens and smaller coiled tungsten filaments allows a brighter and more luminous source. This results in a smaller, more compact, and brighter projected beam pattern with more light at the top of the beam, compared to the relatively inferior non-halogen headlamps. The center of the high intensity zone is closer to the top cutoff of the beam. The beam is more compact from top to bottom, with the center of maximum beam intensity (MBI) located closer to the top of the beam than the bottom, in the range of 1.5 to 2 degrees below the horizontal. This was not the case in the older headlamps. In the standard incandescent designs, the MBI was located farther down from the top of the beam pattern, frequently at 2.5 and even 3 degrees down. The gradient continued to increase and provide more light on obstacles located lower in the beam.

The gradients commonly found in modern halogen lamps have already had their most significant effect at locations of zero to 1 degree down. Placing an obstacle lower in the beam pattern by elevating the lamp's mounting height has a diminished effect. A corollary statement might be that some lowering of the mounting height will have a much smaller effect on the light falling on the obstacle than would have been the case for earlier headlamp designs. (It is worth noting that at some point, raising the mounting height will place the object on the downside of the gradient and there will actually be less light falling on the obstacle.)

6. GLARE REDUCTION CONSIDERATIONS FOR TRUCK VEHICLES

While most arguments point out the negative effects of having the driver’s eyes at elevated heights, few recognize the countervailing advantages. High-density traffic situations are the most critical for drivers for two reasons. Firstly, there is a loss of visual acuity due to glare and the resultant reduced dark-adaptation levels. Secondly, the traffic density may make alternative means of prolonging the observation time more difficult. In this situation it is easy to argue that driver needs are most critical.