SAE International

SURFACE VEHICLE DRAFT TECHNICAL REPORT

SAE J2584 FEB2011

Issued 2002-09
Stabilized 2011-02

Superseding J2584 SEP2002

Headlamp Mounting Height for Passenger and Pickup Truck Vehicles

RATIONALE

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

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE Road Illumination Devices Standards Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

1. ***Scope—*** The Mounting Height Task Force was tasked to determine the extent of the problem(s) associated with vehicle headlamps mounted at or above the level of the mirror(s) in passenger vehicles; the level of glare exposure caused by high-mounted headlamps; the appropriate height differential needed to maintain a glare level consistent with past and/or current passenger vehicle headlamp mounting; and the necessary headlamp mounting height necessary to control mirror glare at an accepted/acceptable level. The report herein addresses these passenger vehicle mounting height issues.

2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J2338—Report of the Task Force on Headlamp Mounting Height for Large Trucks

SAE Paper #740962 1974—Miller, Baumgardner, Mortimer, “An Evaluation of Glare in Nighttime Driving Caused by Headlights Reflected in Rearview Mirrors”

SAE Paper #970911 (1997)—Kosmatka, W., 1997, “Comparison of Models for Detection of Highway Obstacles with Headlamps”

2.1.2 UMTRI PUBLICATIONS—Available from UMTRI, RIPC, 2901 Baxter Road, Ann Arbor, MI 48109-2150. Email: umtridocs@umich.edu, 734-764-2171.

1. Sivak, Flannagan, Traube, Kojima, UMTRI 97-23, The Influence of Stimulus Duration on Discomfort Glare for Persons With and Without Visual Correction, Univ. of Mich. Trans. Res. Inst., May 1997
2. Sivak, Flannagan, Kojima, Traube, (1997). A market-weighted description of low-beam headlighting patterns in the U.S. Report UMTRI-97-37. Ann Arbor: The Univ. of Mich. Trans. Res. Inst.
3. Rumar, Sivak, Traube, Miyokawa (1999), Nighttime Visibility of Retroreflective Pavement Markings from Trucks Versus Cars, No.UMTRI-99-34, Ann Arbor, Univ. of Mich. Trans. Res. Inst.

2.1.3 OTHER PUBLICATIONS

a. Olson,P, Sivak,M., Glare from Automobile Rear Vision Mirrors, Human Factors, 26(3), 269-282, 1984
b. Schmidt-Clausen, Bindels (1974) Assessment of discomfort glare in motor vehicle lighting. Lighting Res. and Tech., 6, 79-88
c. Kosmatka, W., Minutes of the Mounting Height Task Force, May 2, 1995, Southfield Michigan
d. Consumer Reports Magazine, Jan – Sept, 1999 New vehicle driving test reports

3. Definitions

3.1 Sport Utility Vehicle (SUV)—Types of passenger vehicles designed with potential for off-road use. They generally have increased ground clearance and are higher than conventional passenger vehicles.

3.2 De Boer Glare Rating Scale—A nine-point scale for describing the relative levels of discomfort glare. Qualifiers, for the odd points, are as follows: 1 – unbearable; 3 – disturbing; 5 – just acceptable; 7 – satisfactory; 9 – just noticeable.

3.3 Luxmeter Cell—A light sensitive transducer capable of turning incident radiometric flux into current or voltage. The device output, in an appropriate electrical circuit, is proportional to the intensity of the incident radiation and can be reported by an output device as “lux,” “foot-candles” or “candela.”

4. Background—In 1996, the Mounting Height Task Force published SAE J2338 addressing the problems with high-mounted headlamps on heavy trucks. The report suggested that headlamp mounting height on these large vehicles be limited to 0.9 m to 1.0 m.

Due to the increased popularity of Sport Utility Vehicles (SUV’s), there is evidence of increase in public awareness and dissatisfaction with mirror glare from the headlamps on these passenger vehicles. NHTSA had indicated an industry need to control this apparent problem with voluntary limits on headlamp placement or rulemaking actions. In May of 1999, in response to public sentiment and at the request of members of the Road Illumination Devices Committee, the chair reconvened the Mounting Height Task Force to evaluate problems associated with small vehicles, including pickup trucks and SUV’s that were specifically omitted from the “heavy truck” recommendations.

The task force reviewed approximately 70 letters written by motorists to NHTSA (excerpts recorded in Task Force meeting minutes of September 1999). In general, the writers express dissatisfaction with glare from high-mounted headlamps (generally) on SUV vehicles. Both frontal and rear glare are mentioned. Side mirror glare is noted along with interior mirror glare. The interior mirror is dimmable at the driver’s option. It was the opinion of the task force, that the location and relative height of the *side mirror represented the more extreme case* in the case of driver discomfort glare. For these reasons the task force focused its investigations on the driver side mirror in the matter of addressing mounting height for headlamps.

5. Review of Discomfort Glare Studies—The task force reviewed several published glare studies as part of reevaluation of headlamp mounting height.

5.1 Foveated Source—Miller *et al.* (1974) used driver voluntary dimming as a measure of the level of glare from a foveated source that drivers were willing to tolerate. They found that 60% of drivers dimmed their headlamps at 360 m (1200 ft) or greater and that another 28% had dimmed them by 180 m (600 ft). Using information about headlamps of that vintage, the authors concluded that drivers would accept near-foveal illuminance of 0.43 to 1.72 lux (the report actually found “0.04 to 0.16 fc”). Miller *et al.* determined that side mirrors were exposed to 1.9 lux for normally aimed headlamps and 11.9 lux for misaimed headlamps.

5.2 Peripheral Source—Olson and Sivak (1984) studied glare from peripheral sources. They found side mirror glare levels just below "admissible" for eyepoint illumination of 2.37 to 8.61 lux (for "long" exposure durations and "short" exposure durations respectively). They also noted *disability effects* for side mirror glare at peripheral eyepoint illumination levels of 7.75 and 75.5 lux.

5.3 Admissible Level—Sivak *et al.* (1997) studied "oncoming" vehicle glare and concluded that the "just admissible" level, (De Boer level 5) and the less than "admissible" level (De Boer level 4) ranged from 3 lux to 4 lux. This study used a controlled glare angle of 3.5 degrees and a controlled glare duration time of 3 s.

5.4 Peripheral Angle—Schmidt-Clausen and Bindels (1974) documented discomfort glare as a function of the peripheral angle to the point-of-focus. They found an inverse relationship of the 0.46 power between the angle of the glare source to the driver's point-of-focus, to the De Boer rating.

6. Acceptable Discomfort Limits for Side Mirror Glare—With the information previously, along with an assumption for windshield losses (10%) and side-mirror/side-window losses (50%), the task force was able to define a range for "acceptable" discomfort glare in various driving situations. The progression of the calculations of acceptable mirror glare is described in Table 1.

a. Miller *et al*: – Direct Glare at the Eyepoint: 0.4 to 1.6 lux near-foveal glare (applying a 90% for "windshield transmittance" for vehicles *circa* 1974 and rounding to the first decimal place)
b. Olson and Sivak – Side Mirror Illuminance: 2.37 to 8.61 lux for approximate De Boer "level 5" side mirror glare ("3 minute" and "10 second" exposure; no side mirror/window transmittance factor)
c. Sivak *et al*. – Duration Effect: Interpolation from "Figure 4" (see Appendix A), long durations increase the discomfort effect by about 1 to 2 De Boer units. *E.g.*, acceptable range for near-foveal glare ranges from 3.0 to 0.8 lux.
d. Schmidt-Clausen & Bindels – Glare Angle: The glare angle algorithm allows calculation of a transfer function of "3.06" to "3.24" for side mirror glare at peripheral angles of 35 to 45 degrees (relative to the 3.5 degree angle in Sivak et al).

6.1 Exposure Duration—Sivak *et al.* propose a glare tolerance algorithm – De Boer glare rating = 5.05 -1.405 log (exposure seconds). The glare tolerance limit, experimentally determined for short duration exposure, is 3.0 lux. The exposure algorithm then allows definition of tolerance at longer exposure times. A 10 to 20 second time would imply a reduction of one De Boer level, so, in order for a driver to tolerate glare for this length of time, the glare must be reduced *e.g.*, De Boer level 6. Similarly, in order for glare to be tolerable for one minute, the implied shift in glare tolerance is 1.8 De Boer units. For a three-minute exposure, the shift is about 2.5 De Boer units.

The time-dependent glare tolerance was interpolated using figure 4 in UMTRI 97-23 (Appendix A) at Discomfort Glare levels of "5" for short duration; "6" for intermediate duration; and "7" for long durations. The interpolation yielded eyepoint illuminance of 3 lux, 1.5 lux, and 0.8 lux respectively.

6.2 Peripheral Glare Tolerance—The glare tolerance levels previously are for foveated glare at the nominal angle of 3.5 degrees (210 arc-min) to the point-of-focus. In order to account for the peripheral nature of the side mirror glare (versus the foveal tolerance values) angular-ratio factors were calculated for angles of 35, 40, and 45 degrees using Schmidt-Clausen and Bindles' algorithm. The algorithm shows that discomfort *glare is inversely proportional to the angle between the point-of-focus and the peripheral glare source (minutes of arc), raised to the 0.46 power*. The implied effect of peripheral glare light is less than that of foveated glare light. The tolerance ratios for the angles previously are 3.06, 3.15, and 3.24 respectively for the three angles previously. The products of the peripheral-glare-ratios and the glare tolerances for different exposure durations are in Table 1.

TABLE 1—METHODOLOGY FOR DEFINING "JUST ADMISSIBLE" LIMITS FOR SIDE MIRROR GLARE(1)

		Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 3 s Exp	Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 3 s Exp	Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 3 s Exp	Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 10 to 20 s Exp	Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 10 to 20 s Exp	Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 10 to 20 s Exp	Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 1 to 3 Min Exp	Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 1 to 3 Min Exp	Sivak, Flannagan, Traube, Kojima (UMTRI 97-23) 1 to 3 Min Exp	Olson & Sivak, 1984 Exposure Duration 10 s	Olson & Sivak, 1984 Exposure Duration 3 Min
Interpolate De Boer level 5 "**Just Admissible**" from UMTRI 97-23, figure 5		*3.0 lux*	*3.0 lux*	*3.0 lux*	X	X	X	X	X	X	X	X
Adjust for **Long Exposure** duration; UMTRI 97-23 algorithm; 1.0 and 2.0 De Boer units		X	X	X	*1.5 lux*	*1.5 lux*	*1.5 lux*	0.8	0.8	0.8	X	X
Peripheral Glare	45 deg	11.3			4.86			2.45			*8.61 lux*	*2.37 lux*
Adjust UMTRI 97-23 data	40 deg		10.7			4.6			2.52		*8.61 lux*	*2.37 lux*
using Schmidt-Clausen &	35 deg			10.1			4.33			2.59	*8.61 lux*	*2.37 lux*
Bindels algorithm.												
Side Mirror Illuminance	45 deg	22.6			9.7			4.9			17.2	4.7
(multiply by 2 for 50%	40 deg		21.4			9.2			5.0		17.2	4.7
mirror & window trans.)	35 deg			20.2			8.7				17.2	4.7
										5.2		
X-bar "**Just Admissible**" (De Boer level 5) Side-Mirror Illumination		21 lux	21 lux	21 lux	9.2 lux	9.2 lux	9.2 lux	5.0 lux	5.0 lux	5.0 lux	17.2 lux	4.7 lux
Task Force's "rounded" number for "**Just Admissible**" **Side-Mirror Illumination**		10 lux	10 lux	10 lux	10 lux	10 lux	10 lux	10 lux	10 lux	10 lux	10 lux	10 lux

1. ***Italicized numbers*** are from the actual study; other values are derived by application of appropriate ratio factors.

6.3 Window and Side Mirror Loss—Assuming a 50% side mirror- side window transmittance factor, side mirror illuminance would be reduced by half. The eye-illumination numbers in Table 1 were doubled to give results in terms of mirror illuminance.

6.4 Agreement with Prior Research—The rounded averages for the "short," "intermediate," and "long" exposure duration levels are summarized in Table 1 as 21 lux, 9.2 lux, and 5.0 lux. The side-mirror tolerance levels found by Olson & Sivak (adjusted for 50% mirror/window transmission) are: 17.2 and 4.7 lux for 10 second and 3 minute exposures. The order of magnitude calculated for short to long peripheral glare exposure durations, essentially agree with experimental results.

6.5 Task Force Selection of Side Mirror Glare Limit—A reasonable level of 10 lux was selected for the side mirror illumination limit. The rationale for this was not an average, but selected in recognition of the realities of driving situations. While 10 to 20 second, "vehicle-passing" situations are no doubt difficult to avoid, long duration, "vehicle-following" situations are substantially more under the control of the driver being followed by a glare vehicle and could conceivably be avoided or minimized. One could argue that objectionable "long-duration" side mirror glare is less likely in this context, than is intermediate duration "vehicle-passing" scenario; *e.g.*, selection of the "10 lux" side-mirror glare limit.

The task force concluded that "*acceptable"* side mirror glare is 10 lux in the majority of driving situations that have intermediate exposure times, less than a minute in length.

7. Side Mirror Illumination from Headlamps—Several studies of side mirror glare were undertaken in order to quantify the actual levels of driver's exposure to side mirror glare light.

7.1 Field Measurements—Mirror illumination measurements were made for eight vehicles engaged in passing or following a test vehicle on Cleveland area expressways. A color corrected Luxmeter cell was mounted at the lower extreme of a side mirror centered at a height of approximately 900 mm (36 in). The vehicle was driven along interstates having a reasonable amount of pre-dawn traffic. At such times as the vehicle was being followed or passed by other vehicles; illumination readings of the side mirror illumination were recorded. The measured mirror illumination levels are listed in Table 2:

TABLE 2—MEASURED MIRROR ILLUMINATION LEVELS

Vehicle Type and Location	Side Mirror Illumination
Heavy truck following in the right lane	5 to 15 lux (during the measurement interval)
Heavy truck following in the right lane	5 to 10 lux
Heavy truck passing on the left	20 to 60 lux (as the vehicle overtook/passed)
Heavy truck passing on the left	5 to 30 lux
Heavy truck passing on the left	5 to 20 lux
Passenger vehicle following in the right lane	3 to 6 lux (during the measurement interval)
Passenger vehicle following in the right lane	3 to 8 lux
SUV's following in the right lane	5 to 15 lux (during the measurement interval)

7.2 Historic Levels of Side Mirror Glare from Sealed Beam Headlamps; Illumination Calculations—In order to help define a baseline of drivers' historical perspective of side mirror glare, levels of side mirror illuminance were calculated using headlamp-to-mirror differential heights of +15 cm (6 in), *i.e.*, mirror is 15 cm higher than the headlamps. (The differential height of 15 cm was based on historic information on passenger vehicle driver eye elevation, originally derived for SAE J2338).

Using a nominal lane width of 3 m (10 ft), a height differential placing the mirror 15 cm (6 in) above the headlamp, the angular location of the side mirror at several following distances was determined. Iso-candela diagrams of typical beam patterns were than used to interpolate the luminous intensity in the direction of the side mirror position; the mirror illumination was calculated using the inverse-distance-squared law. The summarized information is shown in Table 3 – "Mirror Height: 15 cm up"

Side mirror illumination for typical headlamp types showed considerable variation with varying distances. The mirror illumination level was relatively low at long following distances and increased as following distances shortened to the range of 15 to 30 m (50 to 100 ft). Within this range, it was relatively constant, but in almost all cases, the higher glare value occurred at 15 m (an example is shown for 9007 in Figure 1).

"Par 56" (Type D) headlamps (Table 3) produced 6 to 7 side-mirror lux. "200 mm" rectangular (Type B) headlamps with standard incandescent filaments produced about 3.4 lux at the side mirror, while the "halogen" version of "200 mm" headlamps produce slightly less than 6 lux. (Summary in Table 3 – "Mirror Height: 15 cm up")

7.3 Side Mirror Glare Calculated for "Average" Replaceable Bulb Headlamps—Glare levels for replaceable bulb halogen sources were calculated using "market weighted average" data from UMTRI report 97-37. Replaceable bulb 9004 (bulb type HB1) headlamp side-mirror illuminance levels ranged from about 4 to 5 lux. For 9006 (bulb type HB4) headlamps, the range was also in the 4 to 5 lux. For 9007 (bulb type HB5) headlamps, the range went from 7 to 11 lux. (Table 3 – "Mirror Height: 15 cm up")

TABLE 3—SIDE MIRROR ILLUMINATION(1)

Mirror Ht. Differential >	15 cm Up	15 cm Up	Same as Headlamp	Same as Headlamp	15 cm Down	15 cm Down	30 cm Down	30 cm Down
Following Distance >	**15 m (50 ft)**	**30 m (100 ft)**	**15 m (50 ft)**	**30 m (100 ft)**	**15 m (50 ft)**	**30 m (100 ft)**	**15 m (50 ft)**	**30 m (100 ft)**
7 in Round (Par 56)	**7.3**	5.9	x	x	x	x	x	x
200 mm Inc. (type B)	**3.3**	3.5	x	x	**11.1**	7.3	x	x
200 mm Halogen (type B)	**5.6**	5.7	x	x	**12.1**	11.2	**20.1**	15.7
9004 (type HB1)(2)	**4.9**	3.9	**7.1**	5.9	**14.0**	10.4	**26.5**	15.1
9006 (type HB4)(2)	**3.9**	4.7	**10.0**	11.6	**31.7**	18.9	**50.2**	27.8
9007 (type HB5)(2)	**11.4**	7.4	**21.7**	12.3	**37.2**	19.0	**51.1**	25.0

1. Values in lux.
2. Photometric grid data is "market weighted average" data from University of Michigan Transportation Research Institute report, UMTRI 97-37.

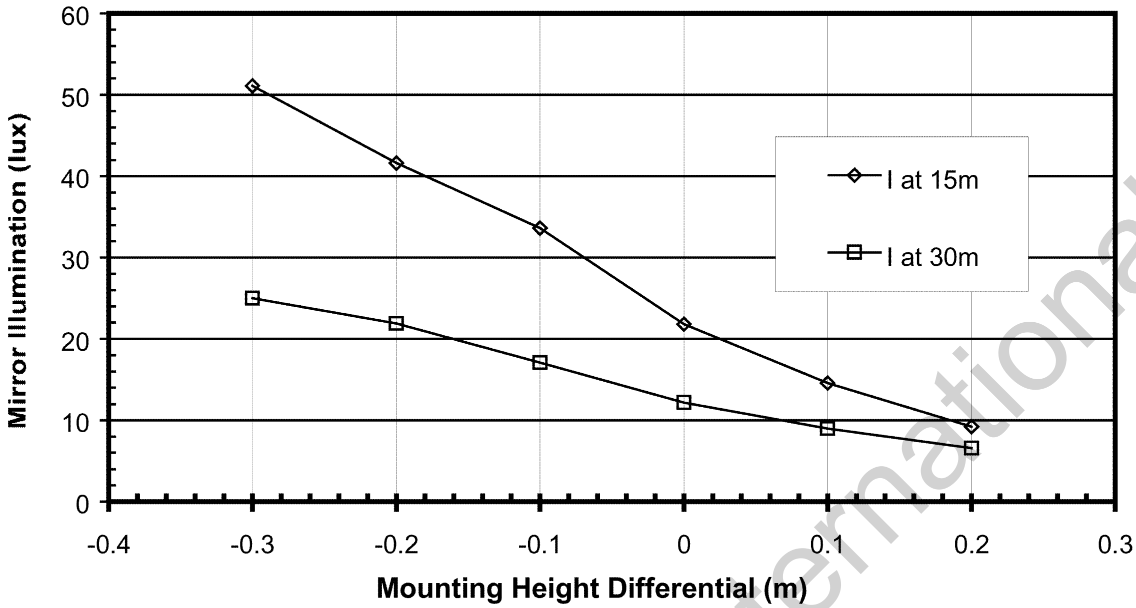


FIGURE 1—9007 MIRROR ILLUMINATION VERSUS HEIGHT DIFFERENCE

7.4 Effect of Elevated Headlamp Mounting Height on Side Mirror Glare—Reference Table 3, “Mirror Height: 15 cm down”/“30 cm down”. When the mirror glare calculations were made for *height differentials of –15 cm*, (mirror 15 cm below headlamp) there was an understandable increase in side mirror illuminance. “200 mm” (Type B) non-halogen headlamps exhibited a modest increase in side mirror glare: 7 to 11 lux; “200 mm” (Type B) halogen-source headlamp glare was higher - at 11 to 12 lux.

Weighted averages for 9004 (bulb type HB1) headlamps were similar to the halogen sealed beam headlamps, with glare rising to 10 to 14 lux. For “weighted average” 9006 (bulb type HB4) headlamps, side mirror glare rose to 19 to 32 lux. Similarly for 9007 (bulb type HB5), glare at the side mirror went up to a range of 19 to 37 lux.

These calculated values appear to be consistent with the range of field measurements (See 7.1).

7.5 Calculations from Actual Vehicle Headlamp Photometric Data — The task force reviewed the relationship between mounting height differential and various halogen source types. The data source was “market weighted average” data. Figure 2 shows that there are fairly wide variations among the various replaceable bulb sources. The “market weighted average” data suggest that some of the newer headlamp styles, incorporating axial filaments, were more prone to producing side mirror glare. Whether this is an artifact of the samples themselves or due to the averaging of light near the gradient has not been determined.

In order to look at the level of variation within a popular headlamp source type, the task force reviewed the side mirror glare calculated from actual photometric data for a sample of late-model vehicle headlamps. Figure 3 compares side mirror illumination, versus the mounting height differential, at 15 m following distance for 5 vehicle headlamps using 9007 replaceable bulbs (bulb type HB5).

While there is considerable variation between within the sample set, it is apparent in Figure 3 that there is less glare light at the “0” and “+10 cm” differential heights than the market-weighted data would suggest. The averaging apparently has some effect in softening the gradients near the horizontal. Inspection of Figure 3 shows that at the point where the headlamp is slightly below the mirror, the side-mirror glare increases at an accelerating rate. The trend is even more apparent when the headlamp is located at or above the mirror height. The break in the curve appears to occur somewhere between 10 and 0 cm vertical separation between the headlamp and side mirror.

Figure 4 compares the lowest and highest glaring of the 9007 (bulb type HB5) headlamps (from Figure 3) with 9004 (bulb type HB1) “market-weighted” glare; calculated glare for one “H7” source lamp; and calculated glare for one “discharge” (HID) source lamp. Inspection of Figure 4 shows that the lowest glare 9007 (bulb type HB5) headlamps is only as good as the (“market-weighted”) average for 9004; and that HID and H7 source headlamps behave similarly to 9007. The break in the glare curve, similar to Figure 3, again appears to be between 0 and 10 cm (0 to 4 in) height differential between the mirror and the headlamp.

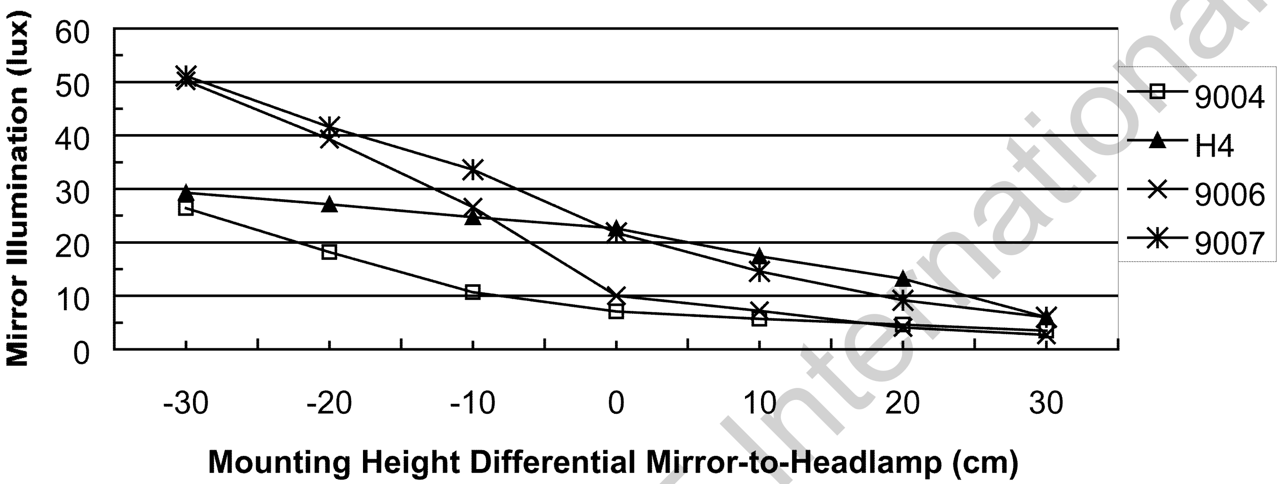


FIGURE 2—SIDE MIRROR ILLUMINANCE AT 15 m FOLLOWING DISTANCE—
MARKET WEIGHTED AVERAGE DATA

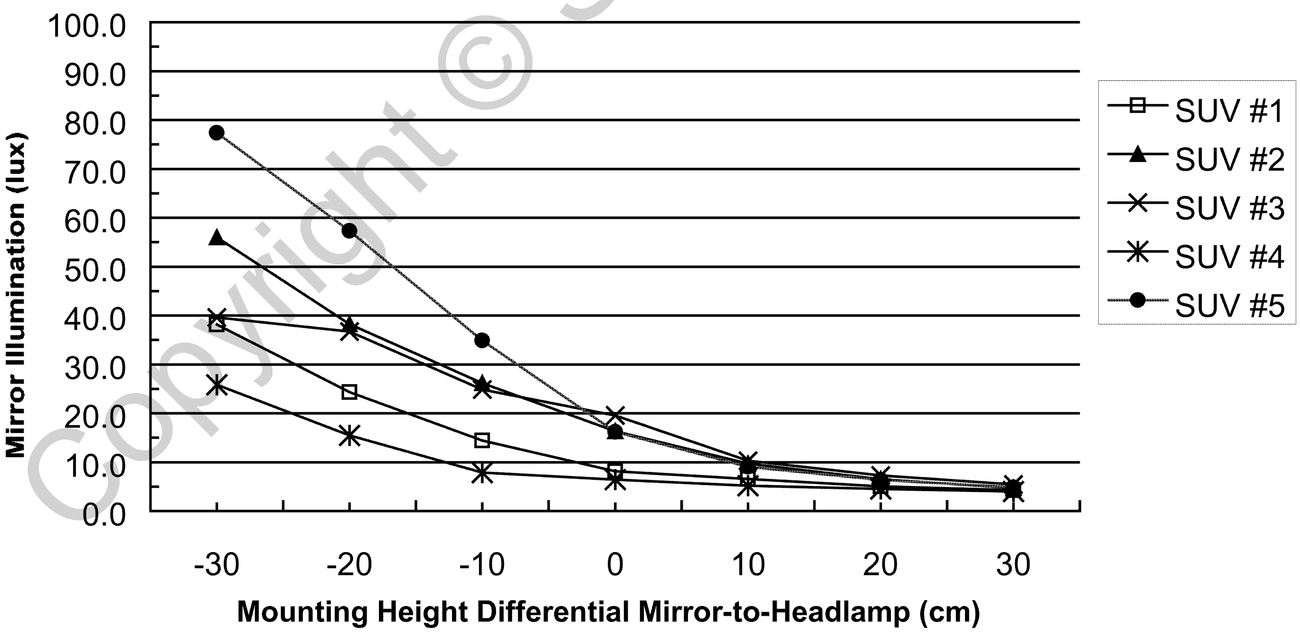


FIGURE 3—9007 SIDE MIRROR ILLUMINANCE AT 15 m FOLLOWING DISTANCE—
SUV VEHICLES

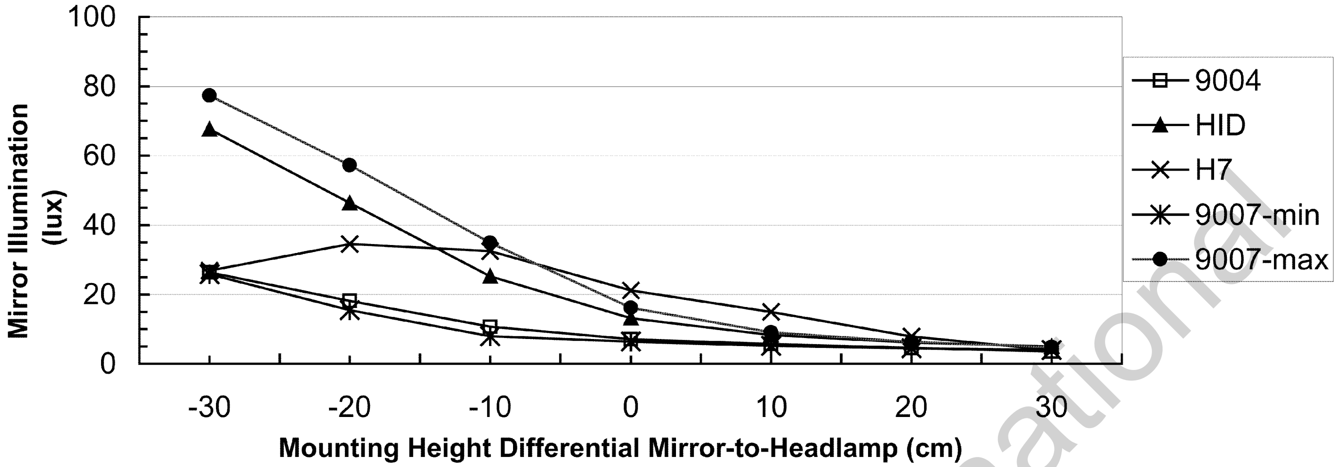


FIGURE 4—SIDE MIRROR ILLUMINANCE FOR 15 m FOLLOWING DISTANCE—
VARIOUS REPLACEABLE SOURCES

8. Other Data Reviewed By the Task Force

8.1 SUV Stopping Distance Data—The question of increased stopping distances for SUV vehicles as a possible justification for greater seeing distance and therefore, higher headlamp mounting, was investigated. The task force compared data (from Consumer Reports magazine panic stop tests on wet and dry roadways) for SUV's and passenger car types of vehicles. It found that there was little if any statistical difference in stopping distance on either wet or dry pavements, between relatively heavy SUV's and lighter passenger vehicles. (See Appendix B.) It does not appear that drivers of heavier SUV's vehicles need a "seeing advantage" with elevated headlamp mounting.

8.2 Mirror Mounting Height—All mirror glare data reviewed by the task force were based on the differential in mounting height between the side mirrors on passenger cars and the headlamps. In order to make a firm recommendation for headlamp location, it was necessary to define the location of side mirrors.

Studies of the distribution of mirror height and aim for a variety of vehicles were made available to the task force (Appendix C). Besides the distribution of mirror heights, the inferred distribution of the "virtual" eye height of passenger car drivers looking into the side mirror was calculated. The average (50th percentile) passenger car driver's eye-height in Appendix C is 940 mm (37.0 in). Given this distribution of passenger car driver's virtual eye location, 85% of passenger car drivers (the 15th percentile) viewing a following vehicle's headlamps would be at or above 895 mm (35.2 in).

8.3 Other Potential Lighting Regulations and/or Restrictions—The task force addressed questions regarding other possible vehicle or headlamp parameters that were inferred to be capable of achieving comparable reductions of glare in side mirrors. These included:

a. Prohibiting certain bulb types
b. Customizing aiming requirements
c. Reducing light above horizontal
d. Reducing vertical gradients
e. Accepting ECE reduced-light-above-horizontal
f. Raising mirror mounting height
g. Requiring driver eye height elevation
h. Requiring only Par 56 (7 in-round) headlamps

8.3.1 AIM MODIFICATION—Aim (2) was discounted because of its impact on roadway/obstacle light. The downward aim that would be necessary to miss a mirror 20 or 30 cm below the headlamp would result in undesirable reduction of roadway and roadway obstacle light. Added to this are other issues regarding proliferation of aim standards, communication and enforcement of these standards.

8.3.2 BEAM PATTERN "SOLUTIONS" TO SIDE MIRROR GLARE—Beam solutions (3, 4, 5) were discussed and it was noted that the mirror light of concern does not (necessarily) come from above the headlamp horizontal. In many case the side mirror of a vehicle on the right is at or below the horizontal centerline of the headlamp. European beam patterns in fact distribute light above the horizontal on the right side of the beam in some if not most instances.

Figure 5 (approximately) illustrates the approximate location of side mirrors for two headlamps over a 15 m to 30 m following distance. In this case, the headlamp is located 30 cm above the mirror. The leftmost line represents the location of the side mirror with respect to the right headlamp. The rightmost line shows the mirror location with respect to the left headlamp.

Inspection of Figure 5 reveals that the side mirror *passes through most of the high intensity zone* (HIZ) of the right headlamp beam pattern. For the left headlamp (the rightmost line), the mirror is located near the right periphery of the HIZ.

A "solution" to the side mirror discomfort glare problem which involved modification of beam patterns would mandate a below-horizontal cutoff. The task force concluded that *restrictions within the high intensity zone were neither in the best interest of the driver nor in the best interests of international beam pattern harmonization* efforts in progress for the past years. Moreover such restriction would lead to reduced lane and obstacle lighting. In the worst case, if such restrictions were tied to either mounting height and/or light source use, a confusing, proliferated, (and probably, functionally unworkable) set of specifications and standards would result.

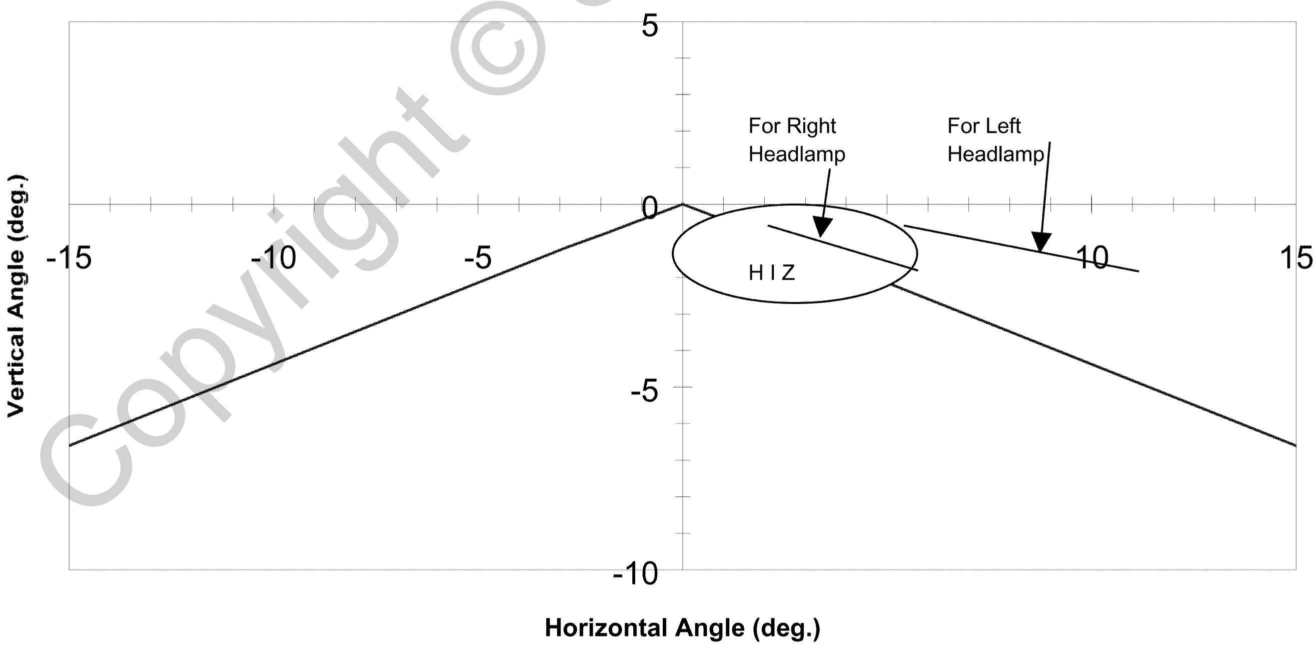


FIGURE 5—MIRROR LOCATION FROM HEADLAMP PERSPECTIVE

8.3.3 HEADLAMP AND/OR LIGHT SOURCE RESTRICTIONS—The task force notes that prohibitions of bulb types or requiring only one type of headlamp (1 and 8) give no guarantee of glare reduction. While it is true that some light sources make it easy to direct more light at the area occupied by side mirrors, there is nothing inherent in the prohibition of one or another light source that prevents headlamp light distributions from the other light source types from also intruding into the mirror area. Moreover it is even possible to argue that the very headlamp light patterns which do the best roadway/obstacle lighting job (9006 and 9007 for instance), tend to cause more side mirror problems than do their less aggressive counterparts.

Light falling in the zones depicted in Figure 5 *is not* an artifact of the headlamp shape, nor the specific nature of the source lamp. Beam design preferences, projected reflector frontal boundaries, light source geometry, and light source orientation with respect to the optical axis of the reflector, are all capable of interacting to influence the level of HIZ light in the region occupied by the side mirror.

8.3.3.1 PAR 56 (7 inch round) Headlamps—PAR 56 headlamps do not cause less mirror glare merely as a result of their shape or size. Filament lumen output/light conservation, high beam emphasis, and restrictions imposed by glass reflector manufacturing techniques and relatively inefficient incandescent filaments, all conspired to restrict light available for the mirror regions depicted in Figure 5.

8.3.3.2 Axial Filament Halogen Light Sources—Halogen sources (such as 9003, 9005, 9006, H7 and H13) allow more efficient use of the filament light output. Given, sufficient reflector area and accommodating periphery geometry, they are capable of high, and arguably desirable, luminous intensities in the HIZ at or near the mirror location. Other source geometries and/or source orientations with respect to the reflector axis, coupled with limitless engineering ingenuity, are similarly capable.

Simple restrictions of light sources or reflector shapes are not in themselves capable of controlling glare intrusion into the region occupied by a side mirror below the vertical centerline of the headlamp; they cannot assure mirror glare control within the multi-dimensional, virtually unrestricted design space. The task force did not view design-restricted headlamps and/or light sources as a viable means of resolving the mirror glare issue.

8.3.4 POSSIBLE INTERRELATIONSHIPS BETWEEN "SEEING LIGHT" AND MIRROR GLARE—Appendix D shows no evidence the side mirror illuminance is related to the seeing light in the right lane at 1/2 degree down – 1-1/2 degrees right.

8.3.5 NON-HEADLAMP-SPECIFIC SOLUTIONS—The solutions involving driver eyepoint/height and mirror location (6 and 7) are outside the nominal purview and experience of the Lighting Committee. The task force viewed these activities tangential to its scope and direction.

8.4 Seeing Distance—The task force reviewed seeing distance data for heavy trucks, (Kosmatka, 1995). A typical halogen 200 mm headlamp beam pattern was used to predict the loss in seeing distance for a 40 cm x 40 cm, 10% reflectance obstacle. As the headlamp height for was reduced from 1.14 m to 0.9 m (45 to 36 in; 20%), the detection distance fell 5% for an expectant driver. Non-expectant drivers, requiring greater obstacle illuminance, would lose 8% in seeing distance.

For passenger vehicles, calculated detection distances for the "average" HB5 system, using a luminance metric for discerning an obstacle (SAE Paper 970911), revealed only a small loss for dark (0.08 reflectance), small (0.4 cm by 0.4 cm) obstacle. When the headlamp height is reduced from 1 m to 850 mm (40 in to 33-1/2 in or 16%), a detection distance loss of 3-1/2% (215 ft to 208 ft) is predicted for an expectant driver. A non-expectant driver would experience about the same distance loss (but a higher percent loss).

Rumar *et al* (UMTRI-99-34) reports results of studies of pavement marking (retroreflective lane stripe) visibility. Detection distance averaged 105.4 m (346 ft) for headlamp mounting height of 1.2 m (48 in) and 93.5 m (307 ft) for headlamp mounting height of 0.8 m (32 in). For drivers of passenger cars with mounting heights of 0.6 m, the average detection distance for the pavement markings was 88.6 m (291 ft). Drivers of vehicles having with headlamps at 0.8 m instead of 1.2 m (–33%) would experience an 11% reduction in lane marking visibility. However, compared to most passenger vehicles with 0.6 m headlamp height, they would still retain a 5% advantage detecting retroreflective pavement marking.

Rumar concludes that mounting height does positively affect visibility of pavement markings but recognizes the implied problem this creates in his final statement: "…higher headlamp mounting heights lead to more glare for both oncoming drivers and preceding drivers via rearview mirrors."

There is a more fundamental question more important than that of a loss in seeing distance. Since data has shown that SUV vehicles have stopping distances approximately equal to that of passenger cars, the need for additional seeing distance for SUV's is difficult to base on a demonstrated safety need. It may be tempting to somehow argue that SUV or pickup truck drivers deserve more seeing distance. However, when one then admits that research has shown this enhancement to be distracting, disturbing or possibly dangerous for drivers in smaller passenger vehicles, the logic may seem self-serving to those outside of the automobile manufacturing industry who don't own SUV or pickup types of vehicles.

The task force could find a demonstrated need for enhancing SUV/pickup "seeing distance" as rationale for mounting height accommodations beyond those for any passenger vehicle.

9. Rationale for the Headlamp Mounting Height Recommendation

9.1 Height Differential—As was noted in the previous sections dealing with glare-acceptance by drivers, an approximate 10-lux level appears to be an acceptable glare tolerance limit for side mirror illumination. This is based on "glare exposure time" and driver's "glare acceptance" studies by UMTRI, and using the algorithm for peripheral glare light offered by Schmidt-Clausen and Bindels).

Lesser levels of glare were once practicable (if not the norm) with older incandescent style sealed beam lamps. New and more powerful replaceable bulb sources have given the designer the option to make significant improvements in roadway light; along with these came some increases in glare. It is the task force's belief that the driving public has accepted the glare increases that accompanied the "halogenation" of the industry, along with the significant improvement in roadway light. In this context the task force defined the side mirror glare limit at "10 lux".

Inspection of the various curves, in Figures 2, 3, and 4, indicates that with some exceptions, the 10 lux glare level occurs when the mounting height differential is between 5 cm and 10 cm *i.e.*, the headlamp center is 5 to 10 cm (2 to 4 in) below the mirror center. The task force also noted the obvious slope change in the glare curve at this point, possibly the result of the beam cutoff located at the H-H line. This accounts for the now-obvious observation that drivers with side mirrors located near or below the horizontal cutoff of a following vehicle with experience significantly more glare than mirrors located above the cutoff.

Figure 3 depicts the variations in the 9007 (HB5) types of headlamps. The glare condition, where the mirror illumination exceeds the desirable limit of 10 lux begins for some lamps at the 10 cm differential, while for others there is no significant glare until the headlamp is 5 to 10 cm above the mirror (–5 to –10 cm on the x-axis). This may be a resultant of the axial light source itself anomalies in the beam patterns/aim of the particular set of samples.

Figure 4 shows that 9006 (HB4) "market-weighted average" lamps do not exceed the 10 lux level until they approach a –10 cm differential. This might indicate that the apparent problem exhibited by the 9007 samples is not inherent in the axial filament orientation, but is be due to other assignable (and correctable) causes such as light distribution design choices, or the state of the art of the 9007-headlamp optics.

In the judgment of the task force, selection of 10 cm differential (*i.e.*, having the headlamp at least 10 cm below the mirror) seemed to be unnecessarily conservative. The task force acknowledged that allowing the mirror to be centered at or below the headlamp centerline (a zero differential), without additional control of the beam cutoff, begs the question of beam pattern restrictions discussed in 8.3.2. Given this understanding as the more fundamental precept, the task force chose 5 cm as the appropriate minimum headlamp-to-eye-height differential.

9.2 The 15th Percentile Driver Virtual Eye Height—The task force reviewed the eye height data and concluded that it was prudent to base mounting heights on the "15th percentile mirror" in passenger cars. This value was chosen as the *nominal mirror height* for the purposes of defining the maximum headlamp mounting height. The use of the 85th percentile in preference to the 50th percentile affects the mounting height by 45 mm (1.8 in). The task force chose the headlamp maximum mounting height to accommodate at least 85% of passenger car drivers. The small height penalty insures that the greater majority of passenger car drivers are accommodated.

The task force rejected use of the 50th percentile for several reasons: First, the difference, 45 mm (1.8 in), is small in comparison to the large percentage of mirrors/drivers that would probably fall below the desired separation distance. Second, SAE past practice has traditionally tried to accommodate at least 80% of the driving (or test) population. And, third, use of the 50th percentile might be viewed as a self-serving means of extending the aesthetic design space at the expense of a portion of the driving public. The percentage of passenger car "driver's discomforted" as a function of headlamp "mounting height" is shown in Figure 6.

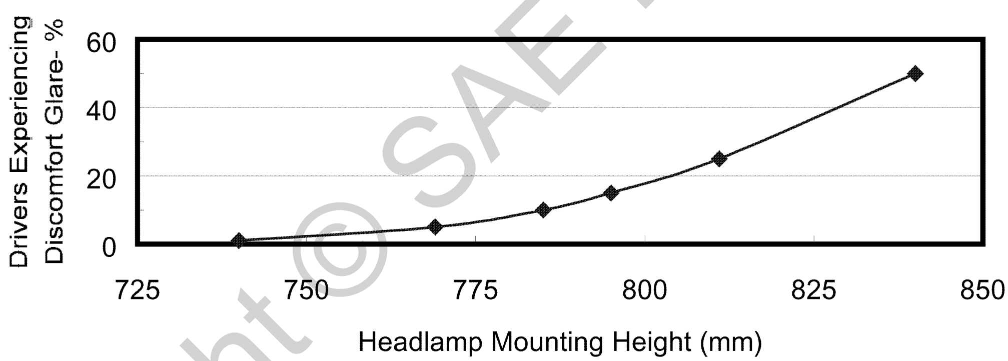


FIGURE 6—PERCENTAGE OF PASSENGER CAR DRIVERS DISCOMFORTED

10. Summary—The Headlamp Mounting Height Task Force studied the ramifications of high headlamp mounting locations used in certain passenger vehicles such as Sports Utility Vehicles and pickup trucks. The task force took into account: (1) historical side mirror glare levels, (2) driver complaints, (3) glare effects attributable to new light sources, (4) stopping distances for heavier SUV's, (5) mirror height statistics, and (6) the advisability of a "beam pattern restriction" solution. The task force concluded, that in the absence of other solutions to reducing side mirror glare, the mounting height of headlamps in passenger vehicles and small trucks, SUV's and pickup trucks, necessary to expose drivers to no more than "admissible" glare levels, is 850 mm (33.5 in).

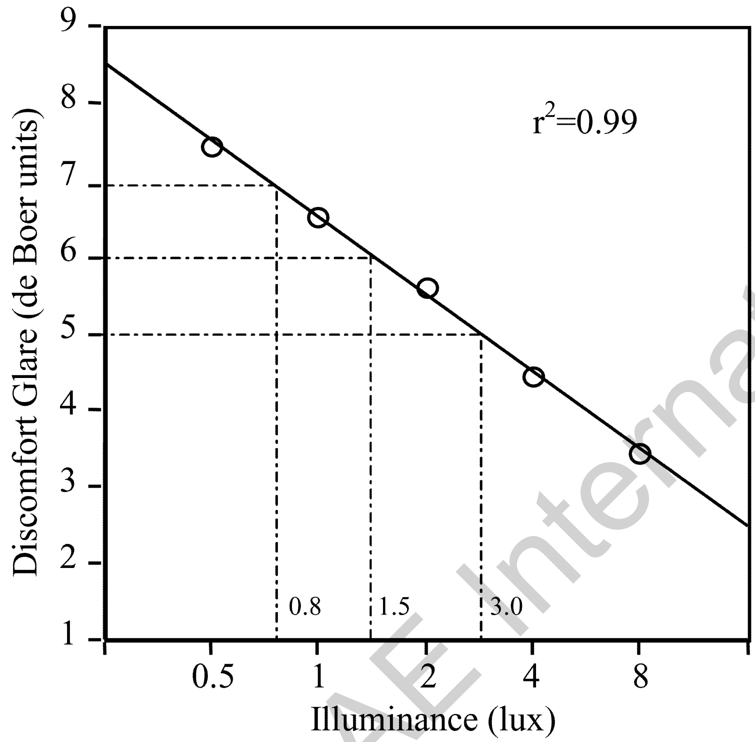
11. Headlamp Mounting Height Guide—With the driver's eye/mirror is located at 895 mm and a mounting differential of 5 cm, side mirror glare considerations suggest that the headlamp be centered at a height no greater than 845 mm (33.3 in), *i.e.*, 895 mm – 5 cm. In order to recognize that manufacturers will normally allow some buffer to accommodate manufacturing variations, and so not as to give undue emphasis to the third decimal place, the task force *rounded the value* for the maximum headlamp center noted above upward, to *850 mm (33.5 in)*.

12. *Implications for Side Mirror Location*—The task force notes that this recommendation is based on the average theoretical side mirror, centered at 939 mm (37 in), and emphasizes that, all other things being equal, vehicles with mirrors below 939 mm will expose their drivers to more (possibly significantly more) discomfort glare than mirrors located above 939 mm.

The task force recommends that in view of the importance of the vertical height of the side mirror in controlling driver discomfort glare, guidelines or standards regarding the minimum mounting height of the mirror be undertaken by the industry.

PREPARED BY THE SAE ROAD ILLUMINATION DEVICES STANDARDS COMMITTEE

APPENDIX A



notes
(1) Interpolated glare tolerance levels for short, intermediate and long exposure durations [UMTRI 97-23, Figure 4]
(2) The effect of illuminance on discomfort glare for 16 subjects (Illuminance is plotted on a logarithmic scale, lower deBoer units indicate more discomfort)

FIGURE A1—EFFECT OF ILLUMINANCE ON DISCOMFORT GLARE

APPENDIX B

TABLE B1—1999 VEHICLE STATISTICS—CONSUMER UNION TESTS

Weight		Vehicle Model	Stopping Distance (from 60 mph) Dry Road	Stopping Distance (from 60 mph) Wet Road
2645	1	Mazda Protégé	144	164
2940	2	Volkswagon Jetta	141	157
2530	3	Toyota Corolla	142	171
2815	4	Daewoo Nubira	145	168
5435	5	Toyota Land Cruiser	148	165
4190	6	Jeep Grand Cherokee	138	166
5850	7	Lincoln Navigator	166	185
4735	8	Land Rover Discovery	148	169
4245	9	Honda Odyssey	142	173
4150	10	Ford Windstar	142	166
3995	11	Mercury Villager	148	179
3285	12	Toyota Camry Solara	140	174
3140	13	Mercury Cougar	138	166
3255	14	Honda Accord	148	162
3005	15	Infinity G20	151	175
3110	16	Mitsubishi Galant	145	178
2885	17	Ford Contour	143	167
3100	18	Olds Alero	147	183
3095	19	Pontiac Grand Am	149	172
3185	20	Daewoo Leganza	153	190
3265	21	BMW 323i	142	164
3345	22	Audi A4	143	159
3460	23	Acura 3.2 TL	139	169
3130	24	Saab 9-3	139	162
3230	25	Suzuki Grand Vista	141	177
3055	26	Chevy Tracker	149	181
3365	27	Kia Sportage	150	193
		Passenger Vehicle Statistics	x-bar= **144**	**169**
			S= 4	9
		SUV Statistics	x-bar= **147**	**175**
			S= 9	8

APPENDIX C

HEIGHTS OF DRIVER-SIDE EXTERIOR MIRRORS AND VIRTUAL EYE POINTS

C.1 ***Method***—Two sets of data were collected (1) 30 vehicles for which driver-side mirror height was measured with a tape measure, and (2) 41 vehicles for which (as part of a larger visibility study) a number of vehicle and driver locations were digitized with a FARO arm, including the driver-side mirror and the driver's eye locations.

C.2 ***Results***—The two sets of data are in close agreement with regard to mirror height, as shown in Tables C1 and C2. The digitized measurements also provide height of the virtual eye point, which is the most important measurement for glare from the rearview mirror. The eye height shown is the midpoint between the right and left eyes. On average, virtual eye heights are very close to the center of the mirror. The standard deviation of eye height is larger than the standard deviation of the height of the center of the mirror because eye height varies randomly above and below mirror height. In these data, the difference between the height of the virtual eyepoint and the height of the mirror is independent of the height of the mirror.

TABLE C1—DRIVER-SIDE REARVIEW MIRROR HEIGHTS ABOVE GROUND

Location	Average Height (mm) and Standard Deviation ( ) Set 1 (n = 30)	Average Height (mm) and Standard Deviation ( ) Set 2 (n = 41)
Top of mirror	988 (48)	986 (36)
Center of mirror	942 (46)	939 (34)
Bottom of mirror	897 (45)	892 (34)
Virtual eye point		940 (43)
Eye height – mirror height		0.66 (26)

TABLE C2—HEIGHTS OF DRIVER-SIDE EXTERIOR MIRRORS AND VIRTUAL EYE POINTS

Percentile(1)	Virtual Eye Height	Mounting Height, mm (in)
1	840	740 (29.1)
5	869	769 (30.3)
10	885	785 (30.9)
15	895	795 (31.3)
25	911	811 (31.9)
50	940	840 (33.1)

1. Percentile of the virtual eye point, and lamp mounting heights 100 mm (4 in) lower.

APPENDIX D

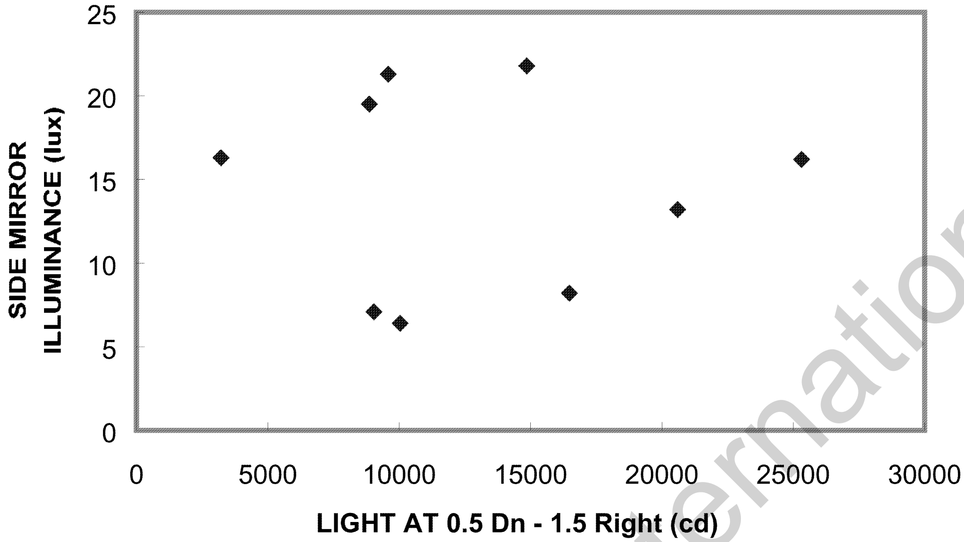


FIGURE D1—SIDE MIRROR ILLUMINANCE (AT 0-DIFFERENTIAL MOUNTING HEIGHT) VERSUS SEEING LIGHT