

# **Forward Vehicular Lighting and Inclement Weather Conditions**

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## **Abstract**

This paper summarizes research conducted to investigate the problem of forward visibility while driving during inclement weather. A review of the literature indicates that using narrow-distribution lamps, mounted away from the driver's line of sight, would result in the lowest amount of back-scattered light. The literature also indicates that the spectral content of light can influence glare and fatigue experienced while driving under these conditions. A series of investigations summarized in this paper confirm the review of the literature and appear to indicate that beam distribution and mounting position offer more leverage to vehicle designers than spectrum, for minimizing discomfort and glare while driving during adverse weather.

## **Introduction and Background**

The essential problem with forward lighting while driving in inclement weather is that of reflected light from snow, rain and fog particles toward the vehicle driver. This reflected light decreases visibility by reducing contrast and by contributing to glare that can lead to fatigue and thus to a higher likelihood of accidents [1]. Visibility in falling snow might be worse than in fog, because the snow flakes present dynamic, rapidly flickering stimuli that may appear brighter than the more even distribution of reflected light in fog conditions [2,3]. Such phenomena could exacerbate discomfort or distraction while driving during inclement weather. Under conditions likely to be experienced by drivers during inclement weather, a review of the relevant literature [4,5] reveals four factors that appear to be most important in affecting visibility and distraction: light source mounting location [6-9], aiming angle [7,10], beam spread [9,11] and spectral power distribution (color) [7,12,13].

## Light Source Mounting Location

Boelter and Ryder [7] measured the reflected light from very narrow beams of light in an artificial fog chamber and demonstrated that as the displacement of the beam from the line of sight (or the photodetector) increased, the luminance of the reflected light from fog particles decreased (Figure 1). The hypothesized implications of these measurements were that a forward light source mounted on a vehicle far from the driver's line of sight would result in improved visibility over the same source mounted very close to the line of sight.

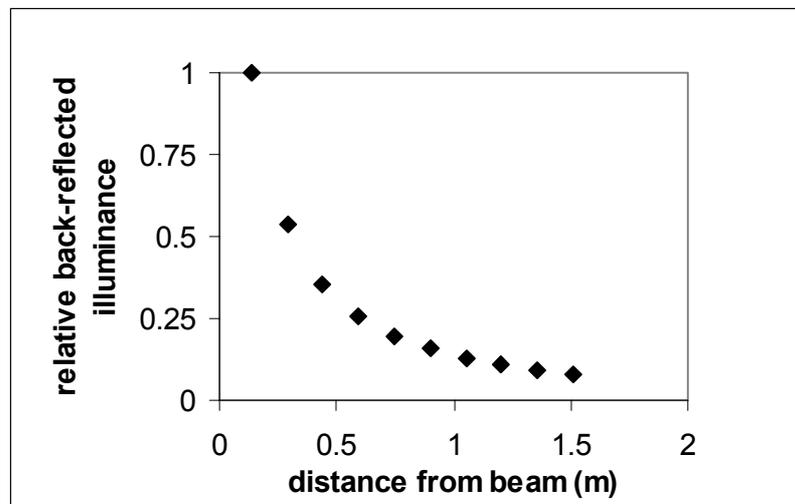
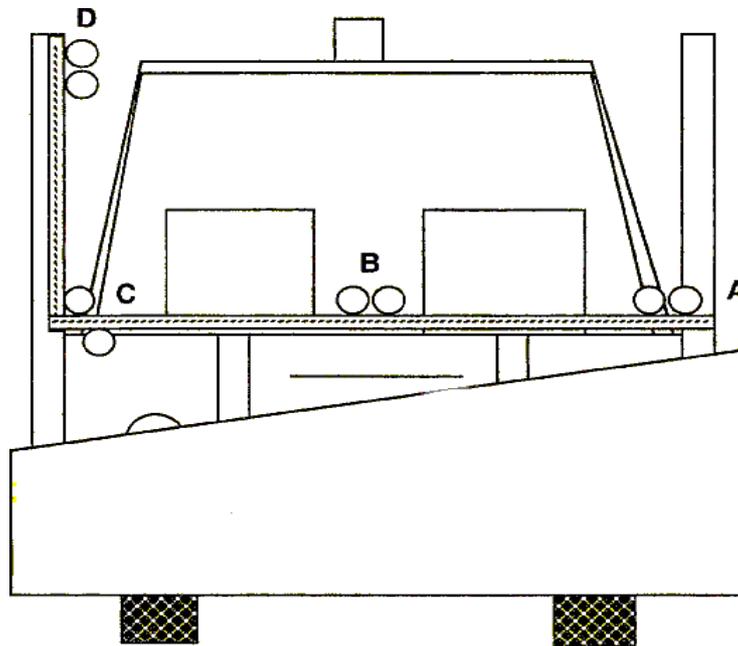


Figure 1. Relative illuminance from back-reflected light from narrow beams of light having different colors in fog, as a function of the displacement from the beam [7].

Bajorski *et al.* [8] measured drivers' ability to see and recognize targets using a wide array of forward lighting packages on snow plow trucks; in general, those configurations with lamps mounted off-axis (away from the driver's line of sight) tended to provide improved visibility, although the configurations did not provide equal amounts of light. A parametric field investigation [9] of light source mounting locations and beam angles (Figure 2) on snow plow trucks showed that visibility and subjective ratings of glare and satisfaction were highly correlated with the mounting position, with locations closest to the line of sight resulting in the poorest visibility conditions (Figure 3). A survey of more than 200 snow plow drivers [6] provided a similar confirmation: as weather conditions

deteriorate, operators tend to rely more on those auxiliary light sources that are mounted furthest from the line of sight (Figure 4).



**Front View**

Figure 2. Mounting locations of forward light sources used by Bullough and Rea on snowplows [9].

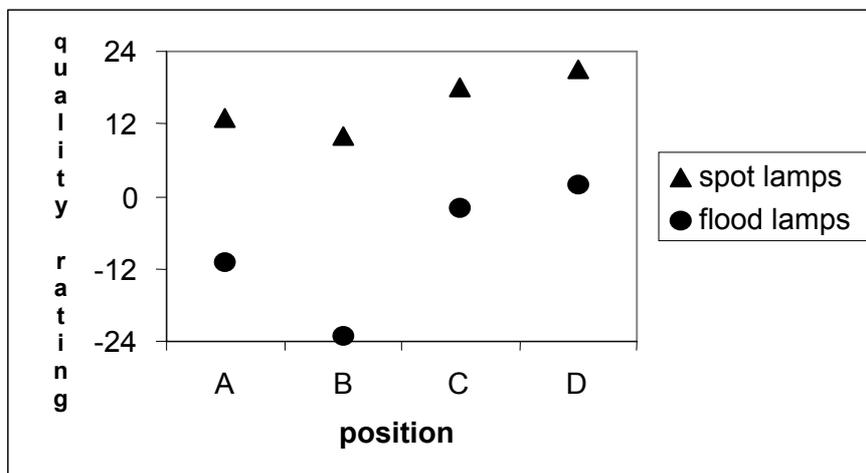


Figure 3. Drivers' subjective quality ratings for spot lamps and flood lamps mounted in the locations shown in Figure 2 [9].

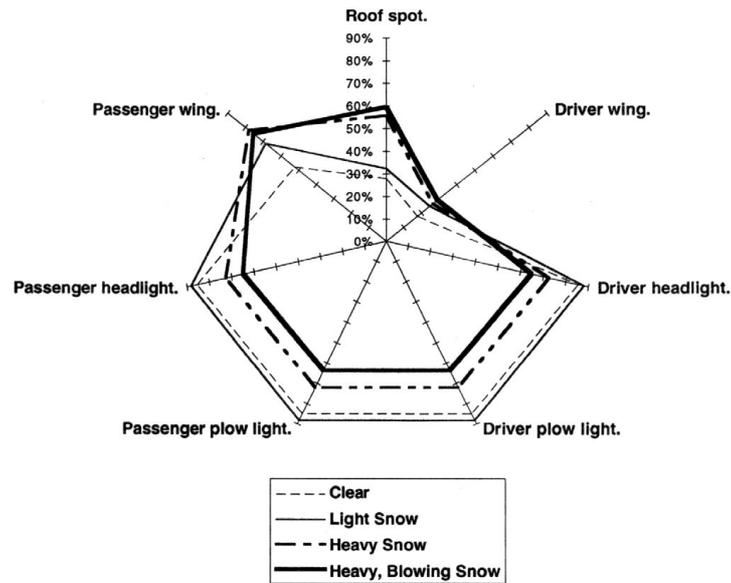


Figure 4. Frequency of reported forward light source usage on snowplows under different weather conditions [6]. The axes each represent the percentage of snowplow drivers using a different light source.

### Light Source Aiming Angle

As for aiming angle, both Boelter and Ryder [7] and Marsh [10] measured the reflected light from a beam of light in fog as the aiming angle of the light source was changed. The luminance of the back-reflected light was greatest when the light source and the line of sight fell along the same direction, and smallest when the light source was aimed approximately 90 degrees from the line of sight. Practically, however, these measurements are not directly relevant to any vehicles because the angle between the line of sight and the beam of light is always quite small.

### Light Source Beam Spread

The beam width of a forward light source can affect visibility because the width of the beam directly correlates with the size of the area from which light is reflected from particles in the atmosphere back to the driver. This concept was reinforced by Hutt *et al.* [11] who measured less back-scattered light from narrow beams than from wide beams in falling snow. Field tests of forward visibility for snow plow drivers [9] found that narrow beams resulted in higher

subjective ratings of visibility and comfort than wide beams because of a reduction in back-scattered light.

### **Light Source Spectral Power Distribution**

The impact of the spectral power distribution (or color) of forward light sources on visibility has been investigated on several fronts. Optically, the amount of light that is reflected from snow, rain or fog particles has been claimed by some researchers to be reduced for amber or red light sources, which contain relatively less short-wavelength light than white light sources. The basis for this claim is Rayleigh scattering, which is inversely proportional to the wavelength, but holds only when the scattering particle size is around the same dimension as the wavelength being scattered (between 400 and 700 nm for light). As particles even in a fine fog average around 8000 nm [7], this effect does not exist for fog and certainly not for snow or rain. Indeed, Boelter and Ryder [7] used various colored filters to measure the reflected light in fog and found no differences among any of the colors used (ranging from red to blue).

Schreuder [12] reviewed the literature related to the issue of yellow and white headlamps in poor weather, and found some evidence that the part of the visual system involved with the sensation of discomfort glare and distraction may be more sensitive to short-wavelength light, and if true, amber sources could be of some benefit provided they give sufficient illumination for visibility. This concept was reinforced in a laboratory study of visual tracking performance while exposed to a field of "visual noise" like that caused by falling snow [13]. Nominally white and yellow light sources with spectra similar to those found on commercially available forward light sources resulted in similar impacts on tracking performance (Figure 5) and on subjective ratings of discomfort and distraction, although sources with output at either end of the visible spectrum showed larger differences consistent with a hypothesized role of rod photoreceptors under such conditions [13].

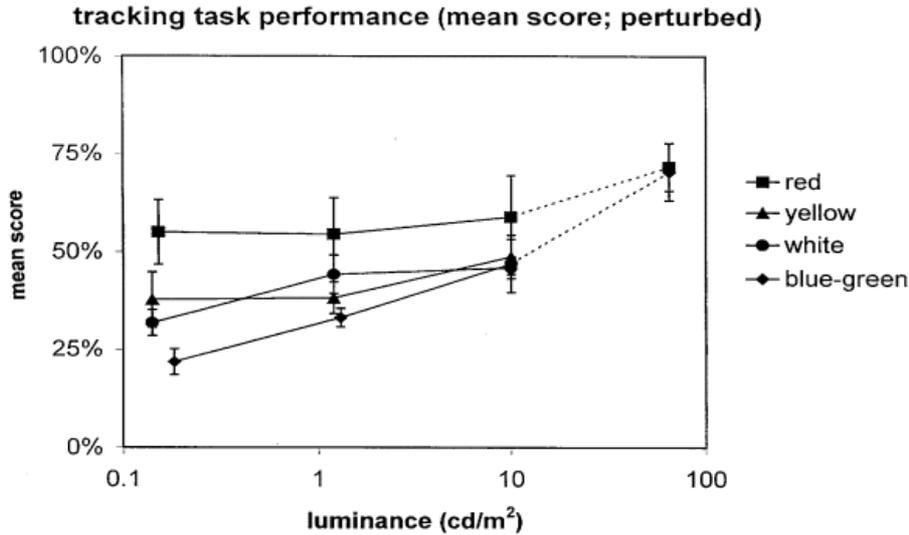


Figure 5. Tracking task performance through "visual noise" simulating heavy snowfall illuminated by different colored light sources [13].

However, once the effects of mounting location and beam width on visibility are utilized to minimize the reflected light as illustrated by Figures 1 and 3, the spectral composition of the reflected light will likely have a small effect on visibility. Spectrum might still offer some leverage, however, when the designer has little latitude with respect to mounting location and beam width.

### Model of Forward Visibility Through Inclement Weather

A mathematical model was developed to predict driver response for different forward lighting configurations while driving in poor weather. Because lamps with high maximum luminous intensities tend to have a narrow beam [9] and because the mounting location of forward light sources affects the degree of back-scattered light [7,9], a model combining these two effects was developed [9]. Drivers' subjective ratings of quality and preference were highly correlated ( $r^2 > 0.9$ ) with the logarithm of the following metric of forward visibility ( $V_f$ ):

$$V_f = I_{\max}d \quad (\text{Equation 1})$$

where  $I_{\max}$  is the maximum luminous intensity (in cd) of the forward light source;  
 $d$  is the distance of the light source from the driver's line of sight (in m).

## Field Demonstration of Forward Lighting in Snow

A simple field demonstration of forward lighting on snow plow trucks was conducted during winter plowing operations in upstate New York, USA, to gauge their relative effects on driver visibility and glare. The demonstration compared two different sealed beam headlamps mounted on the driver's side of the trucks: a conventional headlamp and a louvered headlamp. The louvered headlamp contains small hexagonal louvers mounted inside the headlamp glass, which reduce stray light above horizontal, and effectively narrow the headlamp beam width.

The average luminance of falling snow in the forward direction was measured from the driver's seating position while a truck fitted with the louvered headlamp was parked in the facility's yard with no other lights in use. Table 1 shows this luminance, the luminance when a standard headlamp on a similarly configured truck was used during the same storm on the same night, and the ambient background luminance with headlamps switched off. (All headlamps were checked for proper aiming before measurement.) With the louvered headlamp, the luminance of falling snow in the forward direction was 40% lower than with the standard headlamp.

| Headlamp                 | Luminance of back-reflected snow |
|--------------------------|----------------------------------|
| conventional             | 1.1 cd/m <sup>2</sup>            |
| louvered                 | 0.7 cd/m <sup>2</sup>            |
| none: ambient light only | 0.2 cd/m <sup>2</sup>            |

*Table 1. Average luminance of falling snow illuminated by headlamps, as measured from the driver's seating position.*

Eight snow plow drivers were asked to rate the visibility and glare from the forward lighting, both with the louvered headlamp and with the standard headlamp, while performing their usual plowing runs. Seven-point scales ranging from -3 (poor visibility/a lot of glare) to +3 (excellent visibility/no glare) were used for the visibility and glare ratings. As seen in Table 2, the mean

visibility rating increased from  $-0.13$  to  $+0.25$ , while the mean glare rating increased from  $-1.25$  to  $-0.25$  between the standard and louvered headlamp, respectively. The change in ratings was statistically significant for the glare rating using a paired Student's t-test ( $p < 0.05$ ).

| Question   | Headlamp     | Mean rating |
|------------|--------------|-------------|
| visibility | conventional | -0.13       |
| visibility | louvered     | +0.25       |
| glare      | conventional | -1.25       |
| glare      | louvered     | -0.25       |

*Table 2. Mean subjective visibility and glare ratings with conventional and louvered headlamps.*

## Conclusions

Previous literature and the mathematical model developed by Bullough and Rea [9], based on the response of drivers during inclement weather, all indicate the benefits that are achievable from using narrow-beam forward light sources mounted away from the driver's line of sight. Field demonstrations conducted during the winter have shown that headlamps with louvers or other means for eliminating stray light, are effective at reducing back-scattered light and improving the subjective response of drivers. This finding is particularly important because moving a forward headlamp away from the driver's line of sight (e.g., moving the driver side headlamp to the passenger side) is unlikely to be permissible in many jurisdictions, and because the resulting asymmetries would likely be found objectionable on aesthetics grounds.

However, such a scheme could be implemented in severe conditions on service vehicles, such as snow plows, tractor trailers, and other vehicle or which aesthetic concerns are reduced. It could also be implemented as an inclement-weather-only system on passenger vehicles in such a way that the appearance of the vehicle is not affected. For example, an auxiliary headlamp could be

mounted within the headlight assembly on the passenger side of the vehicle, while providing a switch inside the vehicle that would allow drivers to turn the driver side headlamp off temporarily (or dim its light output) while simultaneously turning the auxiliary passenger side headlamp on. This would have the overall effect of reducing back-scattered light toward drivers during extremely inclement conditions without reducing the total forward illumination.

The development of adaptive forward-lighting systems (AFS) for vehicles [14] also offers promise for the modification of forward lighting distributions optimized for inclement weather, and the concepts outlined above can be adapted quite easily into such systems. Indeed it is likely that AFS systems in the future will include automatic sensors to detect inclement weather and automatically modify the forward lighting distribution (and its spectral content) accordingly. Using the principles outlined in this paper, such systems will likely minimize discomfort and distraction, and can probably provide tangible benefits to individuals required to drive during inclement weather.

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