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16. Abstract

This report covers the historical development of automotive headlighting and describes the differences between European and American concepts in terms of photometrics and construction. The advantages and disadvantages of each system are described.

The main section of the paper is a description of research comparing European and American headlighting systems. There are a number of such studies. The most usual finding is one of small or no differences in seeing distances. The few studies which report larger differences do not agree which system is better.

It is concluded that there is presently no objective way of determining which headlighting system is better. What is clear is that headlighting is a complex subject and the available research evidence, even if it favored one system or the other, covers only some aspects of the problem.

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INTRODUCTION

This document reports the results of a review of the literature on vehicle headlighting. The effort was mainly concerned with the effect of different patterns and intensities of beams intended for use when meeting another vehicle (low beams, meeting beams). The intent was to describe, evaluate and summarize the available evidence concerning the relative merits of alternative vehicle lighting systems.

At present, "alternative vehicle lighting systems" means American versus European. As this report shall shortly make clear, the two systems differ substantially, and in ways which even a casual observer should notice. But, is one system better than the other? It is easy to find persons who think so. For example, Kyle Given, writing in Motor Trend in July, 1972, opens his article as follows:

> "The real fact is this. Americans are driving around with headlights that were made standard more than 30 years ago--the ever popular, certainly vivacious and charming and effervescently bubbling, sealed-beam headlamp unit."

Several paragraphs later he also says:

> "Europeans are currently using better and more powerful forward illumination...systems."

In another article in Road and Track (May, 1973) John Dinkel opens with the following thought:

> "Though they probably don't know it, most American drivers are driving faster on rural roads and freeways at night than their headlights allow them to drive safely. It's a natural chain of events that has brought this about so gradually that hardly anyone has noticed it: roads and cars have improved, so speeds are higher. But U.S. headlights are still a product of the 1940s."

Messrs. Given and Dinkel would probably not qualify as authorities in night visibility and/or headlighting. It is possible that they have fallen victim to the kind of thinking which says that anything which is foreign, more powerful, or makes use of new technology is better. Their opinions may help the sales of European headlamps in this country, but should not be regarded as definitive. Unfortunately, persons who do qualify as authorities in the area disagree strongly as to which system is better. As a result there is some confusion regarding headlighting, not only among the engineers and scientists who work in the area, but among those who make and enforce the laws governing the use of such equipment.

As a start in dealing with this subject it would be well to address a fairly obvious question, namely, "how did such different systems come about in the first place?" The answer is found in the way the automobile developed as a form of transportation in this country and in Europe. Briefly, this happened as follows:

Prior to World War I the development of the automobile followed a parallel course in Europe and in the United States. However, after World War I the automobile rapidly became a dominant form of transportation in the United States. This did not happen in Europe until after World War II. At the same time, many European cities developed fixed lighting systems which provided much higher levels of illumination than those typically found in this country. It is actually possible to drive at night without headlamps in some European cities. Indeed, this is the law in some areas. As a result, of the circumstances described, in the interval between the two wars, driving conditions were generally quite different in the U.S. and Europe. For urban driving, Americans had need for more powerful low beams because of the lower illumination levels. Not only did the European have less need for headlamps to see well in cities but there were more pedestrians and cyclists present and it was thought desirable to protect them from glare. When driving outside of cities, Americans typically encountered traffic conditions which made a very powerful high beam impractical. The fact that much high speed driving had to be done on low beams was further reason to make them as powerful as possible. On the other hand, the European, once outside the city, typically found it possible to drive substantial distances without encountering much traffic. Very powerful driving beams were reasonable under these conditions.

Since World War II conditions have changed greatly. The automobile has become a dominant form of transportation in Europe and in other parts of the world just as it has in the United States. The European is now confronted with roads which are as crowded as those in this country and can use high beams no more often than can the American driver. These changes have made driving conditions more similar in the U.S. and Europe. There have been changes in the lighting systems as well, changes which have made them more alike. Still, in basic philosophy, the systems differ substantially. There is probably no test program which can be devised to resolve all the questions which have been raised or change the strong opinions which have been formed. Hence, the differences will persist.

This paper will attempt to provide information which will enable the reader to become familiar with the various problems in vehicle lighting and the research evidence on the subject which is most often cited. To do this the following sections will provide a brief history of headlamp development, a description of differences in American and European systems, an overview of the experimental literature and a summary and recommendations. An annotated bibliography is included as an Appendix.

HISTORY OF HEADLIGHT DEVELOPMENT

Introduction

The history of headlight development has been treated in depth by a number of authors (e.g., Nelson, 1954; Moore, 1958; Roper, 1957; Kilgour, 1960 and Meese, 1972). A brief summary of this information shall be presented here for purposes of historical perspective.

Headlighting in the United States

In the earliest days of motoring, cars typically carried no lights at all. When lights were first incorporated on vehicles early in the century they were primarily for marking purposes. Headlights first appeared about 1906. They used acetylene and, like the first electric lamps which became available later, had a "beam pattern" much like a search light. The next significant development, which occurred about the time of World War I, was an effort to spread the light from the headlamps to more adequately illuminate the road. This was done by moulding prisms into the lens and produced the first "beam pattern" that might properly be called such. Further developments continued, resulting in substantial improvements in light distribution and intensity.

Unfortunately, in this era there was a proliferation of beam patterns, lamp sizes and shapes which not only made headlighting expensive, but made it difficult to replace components when necessary.

In the middle 1930's work began toward the development of what we know today as the sealed beam, a concept which first was introduced on 1939 model cars. The sealed beam is probably the most significant single development to occur in headlighting. It solved some serious problems associated with aging of the lamp unit, virtually guranteeing consistent, good quality headlighting throughout the life of the vehicle. At the same time, standardization resulted in an area where standardization was greatly needed, resulting in high quality, readily available, low cost headlamps for all vehicles.

The next major advance occurred in the 1955 model year, when an improved sealed beam was introduced featuring a "fog cap" over the filament to reduce upward scatter of light. In 1956, mechanical aiming was introduced as a feature on sealed beam units.

The four headlamp system was introduced on some models of 1957 cars. This system reduced the need for compromise in lens design and filament position necessitated by using the same unit to produce both low and high beam. Interestingly, the first four headlamp system was demonstrated in the middle 1930's. It was rejected at that time for a number of reasons including styling considerations. However, by the mid-fifties things had changed to the point where stylists were among those advocating the four-headlamp system.

In 1959 a new two-headlamp system was introduced, featuring a significantly improved low beam. This low beam was equivalent in performance to that produced by the four-headlamp system, although the high beam could not quite match the performance of the four-headlamp system. In 1970 further improvements in light output were realized for both the two- and four-headlamp system through the use of higher filament wattages.

Headlighting in Europe

The history of European headlight development generally parallels that of the American experience. The most significant difference came about with the development of the so-called Graves "anti-dazzle" bulb, which was patented in 1920. The concept was adopted for use in England and became known as the Lucas-Graves system, in Germany as the Osram-Bilux system and in Holland as the Philips-Duplo system.

The Graves bulb provides a simple and inexpensive way of greatly reducing the amount of light scattered above horizontal. A metal shield surrounds the front, sides and bottom of the low beam filament, preventing any light from being projected directly forward or to the lower portion of the reflector. While this reduces the efficiency of the lamp in terms of total light output relative to the American system, much of the light which is lost would have been projected above horizontal, where it could cause glare. This system results in a beam pattern characterized by a very sharp horizontal cut-off. Compared side-by-side with an American low beam, it is significantly less glaring.

In 1953-54 a number of lighting tests were carried out under the auspices of the CIE (Internation Commission on Illumination). These tests have been described by de Boer (1955, 1956). As part of this program comparisons were made between American and European lighting systems. The results suggested that visibility distances on the left side of the road were comparable under most conditions tested. However, since the American low beam was asymmetrical (i.e., it directed the most intense portion of the beam to the right), it produced greater visibility distances on the right side of the road. As a result, it was recommended that changes be made to the Graves bulb to allow a greater amount of light to be projected up the right edge of the road. This was accomplished by removing a portion of the shield on one side. The sharp cut-off characteristic was retained. However, instead of presenting a flat top symmetrical appearance when projected against the wall or screen, it now appeared flat on the left with a 15^0 upward slant on the right (see Figure 1). This revised concept then became the European standard.

More recently a further modification has taken place, with the high intensity portions above horizontal being cut off at $+1^0$. This produces a shape approximating the letter "Z," instead of a shallow V. This change reduces problems with glare on curves and into the rear view mirrors of vehicles ahead.

The next major advance in European headlighting came with the introduction of iodine (halogen) sources. The first mention of these in the literature occurs in the early 1960's, although their introduction did not come until sometime later.

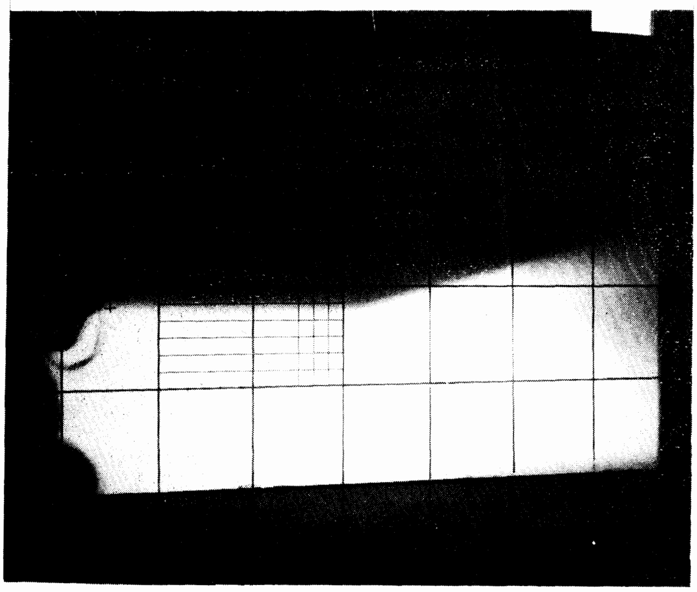


Figure 1. Photograph of Typical European Low Beam
Projected on an Aiming Screen.

The use of iodine vapor inside a light bulb makes possible a chemical reaction which causes vaporized tungsten to redeposit on the filament itself rather than on the glass envelope. Thus, the problem of bulb blackening is eliminated. It also makes it possible to generate substantially more light per watt and use a smaller filament, which simplifies the problem of focusing the beam. Because the filament must be run at a much higher temperature in order to operate the chemical reaction just described, it is necessary to use a quartz envelpe on the bulb. It is for this reason that such sources are termed quartz-iodine or quartz-halogen.

Substantial development has taken place in the last several years since the quartz-halogen concept was first introduced for use on headlamps. Earlier versions could use only a single filament in the bulb, making it applicable only for four headlamp systems. Present day versions incorporate two filaments, so that both high and low beams can be generated from a single source, making quartz-halogen sources more practical for use on the typically smaller European vehicles.

HEADLAMP DESIGN

Basic Problems

The design of vehicle headlamps is a matter of trying to achieve the best possible relationship between glare and illumination. It should be immediately obvious that these two criteria are in conflict, since more illumination will result in more glare. The problem is more complicated than would appear though, since the effects of both glare and illumination are nonlinear.

Most persons are familiar with the fact that the illumination of a surface varies as the square of the distance to the source. Thus a surface two feet from a source will be illuminated at one-fourth the level of a surface one foot from the same source. If the distance were doubled again, to four feet, the level of illumination would fall to one-sixteenth. Thus, to maintain the same level of illumination on an object at twice the distance requires four times the light output. This does not mean that quadrupling headlamp output will double seeing distance. A variety of other factors such as atmospheric attenuation, change in level of adaptation, and changes in background characteristics have a significant bearing on the distance at which a driver will be able to see a given object. As a result, seeing distance under night driving conditions increases much more slowly than would be predicted based on the distance squared law. The point is that additional seeing distance cannot be bought easily, even when glare effects need not be considered.

But glare effects generally must be considered. (glare reduces the ability to see, which is called disability glare, and can produce sensations of discomfort, which is called discomfort glare.) The disabling effect of glare is also quite nonlinear, and the relationship is such that small amounts of glare produce substantial seeing distance losses. This is well illustrated in Figure 2, taken from Moore (1958). For example, for the situation given in the figure, if 20,000 cd are directed toward the target and only 2.5% of

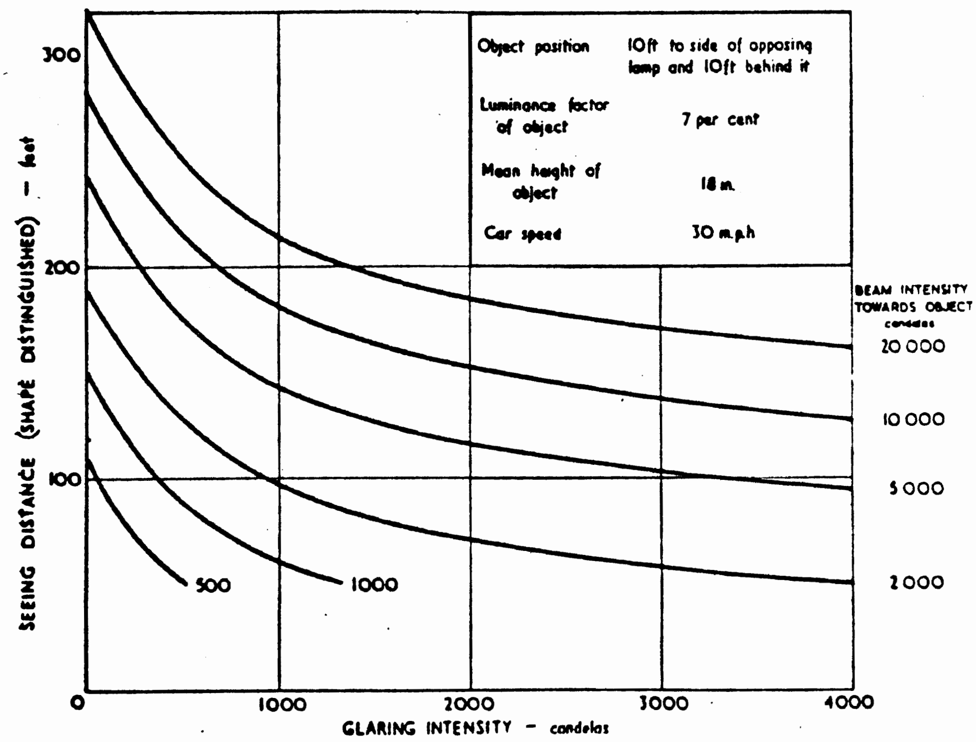


Figure 2. Relationship between the intensity of light directed toward a target and toward an observer's eyes on visibility distance. (From Moore [1958]).

that level toward the driver's eyes, seeing distance will be reduced by 15-20%. Thus, even modest increases in lamp output in an effort to improve seeing distance increase the likelihood of providing disability glare levels that may largely or entirely eliminate the hoped-for gains.

The curves also suggest that one can greatly increase illumination levels to arrive at a flatter portion of the disability glare curve. Some of the studies to be reviewed have investigated this effect. The results are mixed. However, even if such an approach seemed to work in an experimental setting, it takes one into the region of discomfort glare. It is questionable whether the general public would tolerate such glare levels. There are also unanswered questions concerning the cumulative effect of such exposure or the effect of facing large numbers of cars so equipped simultaneously in heavy traffic.

In sum, headlamp design presents some hard choices. Barring a technical breakthrough, it seems unlikely that a meeting beam can be designed which will provide adequate seeing distance under all reasonable conditions of operation. This is a point which seems to be overlooked in the controversy over lighting systems. In the final analysis neither low beam is adequate for safe driving at freeway speeds.

Differences in European and American Headlamps

American and European headlamps differ in terms of photometrics (i.e., distribution and intensity of illumination) and construction.

Photometrics. Until recently, American high beams were limited to 75,000 candelas (cd) maximum from all sources combined, while European high beams could produce as much as 300,000 cd. The maximum for the American system has now been increased to 150,000 cd, although at present this applies only to the larger rectangular units. The European maximum remains at 300,000 cd as of this writing. Recommendations have been made to reduce output to 250,000 cd or less, and are expected to be implemented in the near future.

The candela figures mentioned above are maxima which, to the best of this writer's knowledge, are not achieved by any units available today. High beams having an output of 150,000 cd will probably be available in American made units within the next few years. If so, they will still be less powerful than many European units, although the difference will be substantially reduced. However, in the opinion of the present author, 150,000 cd will provide adequate safe stopping distance for all driving conditions and legal speeds (or illegal speeds, for that matter).

For the American motorist, at present and for the near future, switching to European lamps is the only way to achieve an immediate and dramatic improvement in high beam intensity. The increase in seeing distance is significant as well. When they can be used, such headlamps are a noticeable improvement over current American high beams.

European and American low beams differ primarily in terms of light distribution. In general, European lamps project substantially less light above the horizontal on the left side of the road and provide higher levels of foreground illumination. If a European low beam is projected on a wall, a very abrupt transition will be noted from areas of high to low illumination, as was shown in the photograph in Figure 1. Under the same conditions, an American low beam will show a distinct oval "hot spot" with a more gradual shading to areas of low intensity. Because the latitude of film is so much less than that of the human eye, this effect is very difficult to capture photographically.

Photometric specifications exist for both low beam systems and are reproduced in Tables 1 and 2 (from SAE J570c and UN agreement E/ECE/324, E/ECE/TRANS/505, Rev. 1/Add. 19, March, 1971). Direct comparisons are made difficult by the fact that different points are measured and different photometric terms used. Table 3 is a

TABLE 1. Photometric Specifications for U.S. Sealed Beams. (From SAE J570c)

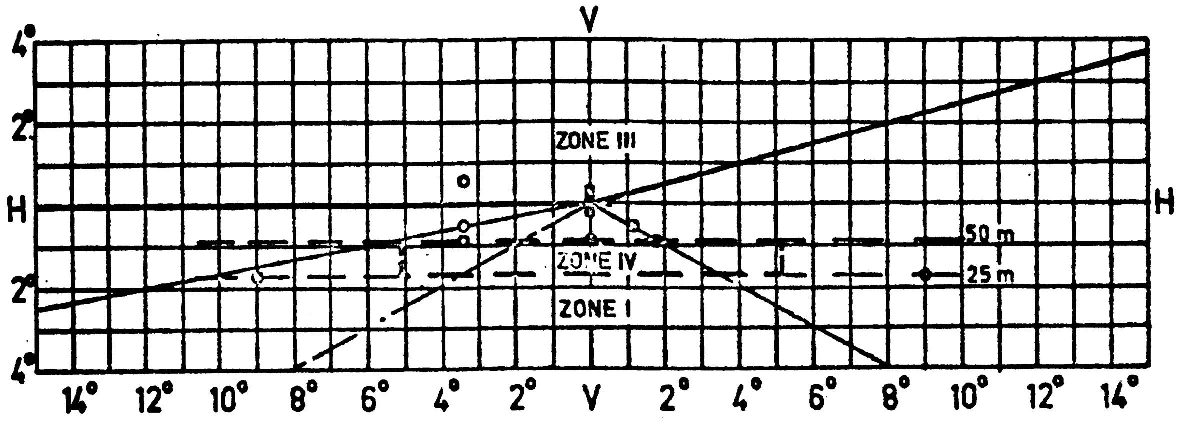
Upper Beam (One 7 in (178 mm) Unit)			Lower Beam (one 7 in (178 mm) Unit)		
Test Points, deg[c]	cd, max[a]	cd, min	Test Points, deg[c]	cd, max	cd, min
2U-V	--	1,000	10U to 90U[b]	125	--
1U-3R and 3L	--	2,000	1U-1-1/2L to L	700	--
H-V	--	20,000	1/2U-1-1/2L to L	1,000	--
			1/2D-1-1/2L to L	2,500	--
			1-1/2U-1R to R	1,400	--
H-3R and 3L	--	10,000			
H-6R and 6L	--	3.250	1/2U-1R to 3R	2,700	--
H-9R and 9L	--	1,500	1/2D-1-1/2R	20,000	8,000
H-12R and 12L	--	750	1D-6L	--	750
			1-1/2D-2R	--	15,000
1-1/2D-V	--	5,000			
1/1/2D-9R and 9L	--	1,500	1-1/2D-9L and 9R	--	750
2-1/2D-V	--	2,500	2D-15L and 15R	--	700
2-1/2D-12R and 12L	--	750	4D-4R	12,500	--
4D-V	5,000	--			

[a] Maximum candela at any test point shall not exceed 75,000.
[b] From the normally exposed surface of the lens.
[c] A tolerance of ± 1/4 deg in location may be allowd for at any test point.

Upper Beam (One Type 1 and One Type 2) or (One Type 1A and One Type 2A)					Lower Beam (One Type 2 or 2A Upper)	
	Type 1 or 1A		Type 2 or 2A			
Test Points, deg[c]	cd, max[a]	cd, min	cd, max[a]	cd, min	Test Points, deg[c]	cd, max
2U-V	--	750	--	750	10U-90U[b]	125
1U-3R and 3L	--	3,000	--	2,000	1U-1-1/2L to L	700
H-V	60,000	18,000	15,000	7,000	1/2U-1-1/2L to L	1,000
					1/2D-1-1/2L to L	2,500
H-3R and 3L	--	12,000	--	3,000	1-1/2U-1R to R	1,400
H-6R and 6L	--	3,000	--	2,000		
H-9R and 9L	--	2,000	--	1,000	1/2U-1R to 3R	2,700
H-12R and 12L	--	750	--	750	1/2D-1-1/2R	20,000
					1D-6L	--
1-1/2D-V	--	3,000	--	2,000	1-1/2D-2R	--
1-1/2-9R and 9L	--	1,250	--	750		
2-1/2D-V	--	1,500	--	1,000	1-1/2D-9L and 9R	--
2-1/2D-12R and 12L	--	600	--	400	2D-15L and 15R	--
4D-V	5,000	--	2,500	--	4D-4R	12,500

[a] The Combined maximum candela at any test point shall not exceed 75,000.
[b] From the normally exposed surface of the lens.
[c] A tolerance of ± 1/4 deg in location may be allowed for at any test point.

TABLE 2. Photometric Specifications for European Headlamps.



Point on measuring screen		Required illumination in lux
Headlights for right-hand traffic	Headlights for left-hand traffic	
Point B 50 L	Point B 50 R	< 0.4
" 75 R	" 75 L	> 12
" 75 L	" 75 R	< 12
" 50 L	" 50 R	< 15
" 50 R	" 50 L	> 12
" 50 V	" 50 V	> 6
" 25 L	" 25 R	> 2
" 25 R	" 25 L	> 2
Any point in zone III		< 0.7
Any point in zone IV		> 3
Any point in zone I		2 x ($E_{50\,R}$ or $E_{50\,L}$) */

*/ $E_{50\,R}$ and $E_{50\,L}$ are the illuminations actually measured.

(From Agreement Concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval from Motor Vehicle Equipment and Parts. Addendum 19: Regulation No. 20 to be annexed to the agreement. Uniform provisions concerning the approval of motor vehicle headlights emitting an asymmetrical passing beam or a driving beam or both and equipped with halogen headlamps (H_4 lamps) and of the lamps themselves. March 1, 1971.)

TABLE 3. Comparison of Photometric Specifications for American and European Low Beams.

United States		European	
Position	Intensity	Position	Intensity
1/2 D 1 1/2 R	20 K Max. 8 K Min.	.57 D 1.15 R	7.5 K Min.
1 U 1 1/2 L	0.7 K Max.	Zone III	0.438 Max.
1/2 U 1 1/2 L	1 K Max.		
1 1/2 D G L & R	0.75 K Min.	1.72^{0} D 9.08 L & R	1.25 Min.
1 1/2 D 2R	15 K Min.	.86 D 1.72^{0} R	7.5 Min.

Units shown are candelas (cd).

comparison, using the same photometric units, of a number of points in the two systems which are fairly close together. The differences in light projected above the horizontal and close to the car should be evident.

Another way of visualizing the lamps is by means of so-called isocandela diagrams. Two such diagrams are reproduced in Figure 3. These are taken from a report by Harrison (1976) and are presented here as reasonably typical representations. The major difference is that the European lamp places higher intensities closer to the H-V axis (0^{0} horizontally and vertically) in the lower right quadrant and lower intensities just above and to the left of H-V in the upper left quadrant. This should result in more illumination in critical areas and less glare in the eyes of oncoming drivers. If this relationship could be maintained in real world driving situations, it should be superior to the American beam. However, the relationship obviously cannot be maintained under all driving conditions and a key argument concerns the extent to which this variability degrades system performance.

Construction. Since 1939 American headlamps have been made as sealed units. That is, the light source, reflector and lens elements are fused into one piece. European headlamps are made as separate units with the lens and reflector glued together, but the light source removable. There are significant advantages associated with each approach.

One of the main advantages of the sealed beam approach originally was that it minimized the effect of bulb blackening. In a conventional tungsten bulb material vaporized from the filament redeposits on the nearest cooler surface, generally the bulb envelope. In a typical automotive bulb, where the envelope is quite small, the result is a pronounced darkening of the bulb over time, causing a drop in light output. Because of the much greater surface area in a sealed beam, this effect is negligible. For European headlamps the problem continued until the introduction of the halogen bulb.

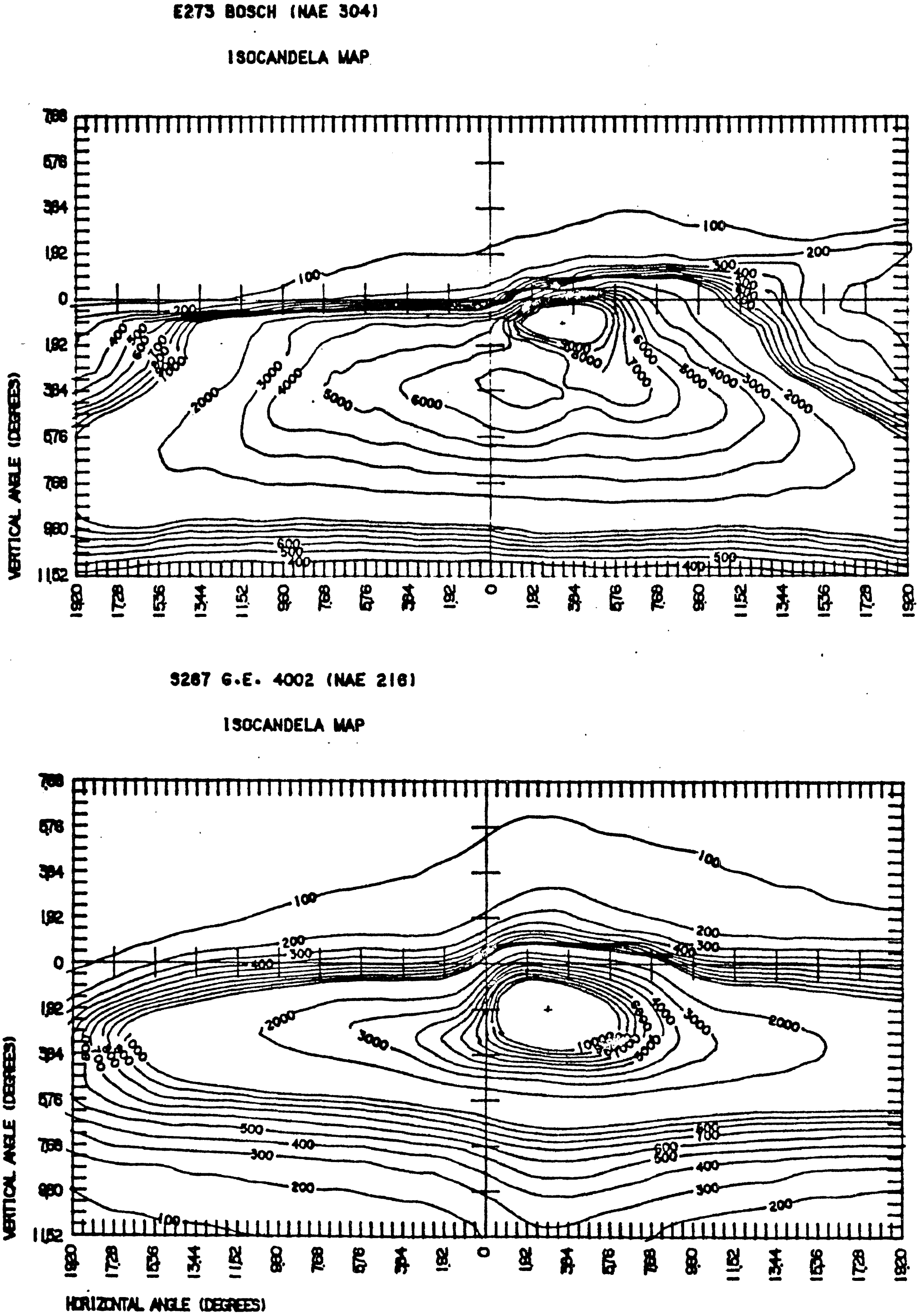


Figure 3. Typical Isocandela Plots for U.S. and European Low Beams. (From Harrison [1976]).

Another considerable advantage for the sealed beam is the elimination of deterioration due to dirt and moisture entering the headlamp unit. While this problem has been reduced over the years in European units, it has not been eliminated. The reason is that such lamps "breathe," driving air out as they heat up and drawing air (along with dirt and moisture) back in again as they cool off.

Contaminants inside the unit and deterioration of the reflector result in reduced overall output and distortions of the beam pattern. If a periodic motor vehicle inspection (PMVI) program exists, measurements of lamp output can be made without great difficulty, although failures may be attributable to electrical problems resulting in low voltage rather than lamp deterioration. Determining when a beam pattern has changed to the point where the lamp should be changed is a much more difficult problem. In the opinion of the present author, there is no basis presently for deciding the point at which a beam pattern has changed enough to warrant rejection. There is certainly no way of measuring the change objectively.

If replacement of a deteriorating lamp is left to the judgment of the owner, it can be anticipated that a large variance in headlamp conditions will result. In part this is attributable to economics and the common human tendency to procrastinate. However, it should be noted that such deterioration is gradual and the change must be judged on an absolute basis. Under these conditions, it is very difficult for the average person to detect a change in the quality of visibility provided by headlamps. Therefore, substantial deterioration and significant loss of visibility is to be expected before even very conscientious motorists will replace the affected units.

The beam pattern of a sealed unit changes with use as well, although documentation of this effect is scanty (Finch, et al., 1969). However, the pattern is restored when the unit is replaced. Replacing the bulb in a composite unit will not restore a pattern which has been altered by internal corrosion, etc.

The use of sealed beams also make it possible to aim the lamps mechanically. As will have been clear from the isocandela diagrams presented earlier, accurate aiming is very important if maximum performance is to be realized. However, accurate aiming is difficult, even under ideal conditions, when done visually (see, e.g., Olson and Mortimer, 1973). Mechanical aimers are simple, inexpensive, easily stored, and more accurate than any other aiming technique currently available for field use.

Composite units, such as European headlamps, cannot be aimed mechanically at the present time. Theoretically, visual aiming can be more precise with a European beam pattern because of the sharp cut-off characteristic. On the other hand, American service personnel are less likely to know how to aim such lamps. There are no data to indicate the quality of aim actually achieved with European beam patterns.

There are advantages associated with the composite concept as well. A chief advantage (in the eyes of many people) is that it makes it unnecessary to throw away a perfectly good lens-reflector unit just because a filament has burned out. This alleged advantage is the subject of some debate. The question is whether, by the time the first burn-out occurs, sufficient internal deterioration has occurred to make it desirable to replace the whole unit. Even if this is not the case, there remains a question as to whether it is wise to allow motorists to use headlamps which will deteriorate over time, thus placing an additional burden on PMVI personnel or vehicle owners to make rather difficult judgments.

It is generally much easier to replace the bulb in a composite unit than to replace a sealed beam. Also, because the bulbs for composite units are small, it is easier for a motorist to carry a spare in the car. These two points <u>may</u> mean that there would be fewer instances of "one eyed" cars on the roads if composite headlamps were used. On the other hand, the quartz-halogen sources used in modern European lamps have a shorter life than U.S. sealed beams. So, there will be more burn outs per unit time, which would tend to work against the advantages listed.

A composite lamp is more likely to continue functioning if the lens should be broken. Obviously, a sealed beam would burn out immediately under such conditions. There is a clear advantage in having a lamp continue to function should the lens suffer damage while driving at night. However, the unit will deteriorate very rapidly after such an event and should be replaced. This again raises the problem of judgment referred to earlier. The fact that a lamp will continue to operate after having been damaged is seen as a disadvantage by some persons. Their argument is that, if the lamp doesn't work at all it will be replaced, thus avoiding the problem of deterioration.

It is sometimes argued that sealed beams can be replaced without reaiming. This is not necessarily true.

There are two approaches to establishing the relationship between the beam pattern and aiming plane on a sealed beam. These are:

1. The filament position is adjusted to cause the beam to correspond to the aiming pads moulded on the lens surface.
2. The aiming pads are ground to define the proper aiming plane as a last step in the manufacturing process.

If one is replacing a unit manufactured in the first way with another identical unit, then the need for reaiming is minimal, if the original was correctly aimed. If a unit manufactured in the second way is involved as the replaced and/or replacement unit, reaiming is possibly necessary. Reaiming <u>should</u> be carried out each time a bulb is replaced in a composite unit.

RESEARCH IN HEADLIGHTING AND NIGHT VISIBILITY

Introduction

Headlighting research has been carried out in a variety of ways. Much developmental work, for example, has been done simply by building experimental lamps, mounting them on automobiles and driving with them to evaluate subjectively the visibility and glare afforded. Some work has been done relatively recently by means of computer modeling. However, the bulk of the published work in the field and, therefore, the bulk of the work which will be referred to in this report, consists of seeing distance studies.

In one sense headlighting research seems a simple issue. Since headlights are designed to illuminate the environment through which the automobile will be traveling, it seems a fairly straightforward matter to place target objects on or near the roadway and measure the distance at which they can be detected by experimental subjects. Variations of this approach have been used by a number of investigators. A wide variety of target objects have been employed. Generally, the task has been to detect the target object but sometimes the task is to determine something about it, such as its orientation. Either approach yields objective data which can be very helpful as a means of evaluating headlamp performance.

Unfortunately, the problem of evaluating headlamp performance is not as simple as it might appear at first. There are several difficulties. One of the major problems concerns the wide variety of real-world conditions under which vehicles are driven at night. For example, most seeing distance studies have been carried out on flat, straight roads. This raises a question concerning their relevance to the hilly, curvy and sometimes bumpy roads over which much driving is done. There are a number of other conditions which have rarely been studied other than in an idealized state.

A second problem concerns the way in which the results are weighted to arrive at beam pattern decisions. For example, seeing distance studies do not answer questions concerning the importance of being able to see certain portions of the road in order to perform the basic control task. The driver needs much more information in order to be able to successfully operate the car than just knowing whether there are objects in or near the path. In the final analysis, much data are required to arrive at a decision regarding the optimum beam pattern, and only some of this information is supplied by the seeing distance study approach.

Finally, there are problems with the research itself in many cases. There are a great number of variables which can influence the actual distance at which a target is seen. Many investigators have been casual about some of these variables. For example, saying that standard American low beams were used tells the reader less than would be desirable about the source of illumination, since there are significant variations from lamp to lamp in the production process. Factors such as headlamp aim and voltage control have sometimes been ignored or given less attention than appropriate. The type of target employed, its position on the road, the subject instructions, the visual characteristics of the subjects, whether the test is conducted statically or dynamically, are all significant variables which, when summed together, possibly account for some of the substantial differences reported.

The result of all of this is that, although a great deal of effort has gone into headlighting research, relatively little in terms of definitive results can be shown. This does not mean that the work reported is without value. It does mean that care must be exercised in drawing conclusions on the relative merits of various beam patterns based on the test data available.

REVIEW OF HEADLIGHTING RESEARCH

This section will review the various investigations which have been concerned with beam pattern development in this country and in Europe. Sixteen different studies were thought important enough to be included. These are presented in capsule form in Table 4. As can be seen from a review of the table, a variety of methods, variables and results characterize these investigations.

A comparison between U.S. and European headlighting systems was the primary purpose of some of the studies to be covered, although generally it was not. When discussing the latter investigations, this review will focus on the data relevant to the topic of interest in this report.

One of the most significant of the early reports comparing American and European beam patterns is that of Harris (1954). He summarizes a great deal of information about headlighting in the era immediately after World War II. The paper contains a report of an investigation carried out at the Road Research Laboratory comparing American, British, and two types of European headlights. The tests Harris describes were semi-dynamic in that the experimental vehicle was moving but the glare source was not. A single target was employed, which was placed 10 feet behind the glare lamps and 10 feet to the left (recall this test was done in Great Britain, where the rule of left applies). The target in this instance was an object 1.5 feet high with a reflective factor of 7%. The target position was selected to be the most difficult to see. Hence the seeing distances measured were minimums. The results from these tests were used to generate curves showing the trade-off between glare and visibility distance for the specified target object. These curves were used to calculate minimum seeing distances for the four beams of interest. The calculated seeing distances are reproduced in Table 5.

TABLE 4. Summary of Studies Comparing American and European Headlighting Systems.

AUTHOR(S)	YEAR PUBLISHED	METHOD	RESULTS
Harris	1954	Subjects moving, static glare source, single 7% target positioned behind glare source. Used symmetrical European beams.	Little difference between U.S. and European beams when properly aimed. European beams more affected by misaim.
Kazenmaier	1956	Report of "Working Group Brussels." Fully dynamic tests, various targets.	European beam gave better visibility to left and poorer visibility to right compared to U.S. beam. Led to modification to European beam.
Jehu	1957	Mathematical analysis based on symmetrical European beam and British standard low beam.	Results depend on target object and viewing conditions. Jehu feels British beam is better due to superior near side performance.
Lindae	1962	Compared U.S. 2 and 4 lamp systems with European asymmetrical system.	Seeing distances to targets on right about the same for the 3 systems. European system 30-50% better for targets on left.
Johansson, et al.	1963	Compared symmetrical and asymmetrical European beams using moving glare car and stationary subjects.	Asymmetrical pattern better. Higher target reflectivity gave longer visibility distance. High beams gave longer visibility distances than low beams in meeting situations.
Fosberry & Moore	1963	Method same as Harris (1954). Compared British beam with asymmetrical European beam.	Results for all test conditions very similar.
Roper	1965	Both subjects and glare source moving. Targets were 16" square, 7% reflectivity. Compared European quartz-halogen and standard U.S. sealed beams.	Seeing distance differences were minor, amounting to 10% more for the U.S. system under no glare conditions. Performance the same under maximum glare conditions.
Faulkner & Older	1967	Method similar to Harris (1954) but target presented a detection and identification task.	European beam produced better detection distances, especially with target very close to glare source. Recogntion distances greater for British beam when target was positioned in front of glare source but greater for European beam with target positions behind glare source.
Rumar	1970	Compared tungsten and quartz-halogen European lamps and static glare source with subjects moving. Small 4% reflective targets at edge of road.	Quartz-halogen better under all conditions tested.
Christie & Moore	1970	Discussion paper.	Argue that European quartz-halogen is better system, _if_ good aiming can be insured.
Hull, et al.	1971	Extensive test program using moving vehicles, variety of targets and lighting systems.	U.S. and European low beams very similar. European high beam better under no glare conditions.
Rumar, et al.	1973	Used static glare source, moving subject car. Subjects detected dark targets at right edge of road. Compared U.S. and European high and low systems on straight and curved roads.	European high beam better under no glare conditions. U.S. low 30-40% better on straight roads without glare but slightly poorer facing glare. On curved roads the systems performed alike except on sharp left curves where U.S. beam was better.
Ohlon & Zaccherini	1972	Mathematical analysis of Rumar, et al., (1973) data.	Results indicate that reason for differences reported by Rumar arise from light projected just below horizontal.
Mortimer & Olson	1974	Dynamic field tests using identification targets. Various beams, target reflectivities, target positions and lateral spacings.	Little difference between European and U.S. systems under all test conditions.
Bhise, et al.	1977	Dynamic field tests and computer modeling to simulate total driving environment.	No significant overall performance improvement associated with any of several systems tested.
Graf & Krebs	1976	Used eye fixations to measure detection distance to targets which had been selected to appear normal to the road environment. Tested several lighting systems.	No differences in detection distance for any of the beams tested.

TABLE 5. Calculated Minimum Seeing Distances for Various Lamps (From Harris [1954]).

Lamp	Seeing Distance		Reduced values due to misaim (per cent)
	Correct alignment	-0.5^0 misaim	
British	158	132	82
American	149	122	82
European B*	150	116	77
European A*	145	109	75

*These were both symetrical beam patterns which differed slightly in distributional characteristics.

These data indicate that, for the conditions specified, the three types of lamp differ relatively little, when properly aimed. The American and British beams, which are generally similar, differ relatively little under conditions of incorrect alignment as well. The European beams, with their sharper cutoff, are more affected by misaim.

One of the most extensive early headlighting research efforts was that carried out by the "Working Group Brussels, 1952." The intent was to arrive at a generally acceptable and improved headlight beam pattern. The program proved to be so extensive that its completion was distributed among the national committees of Germany, England, France, The Netherlands, and the United States. For purposes of this survey the most significant results are summarized in Figures 4 and 5, which have been adapted from Kazenmaier (1956). These curves show visibility distances measured for the symmetrical European beam in use at that time meeting a similar beam, as well as for an American sealed beam meeting a similar beam. It will be noted that the European beam afforded significantly greater visibility down the left side of the road. The two beams were similar for objects in the center of the road. However, the American beam provided significantly greater visibility distance down the right side of the road.

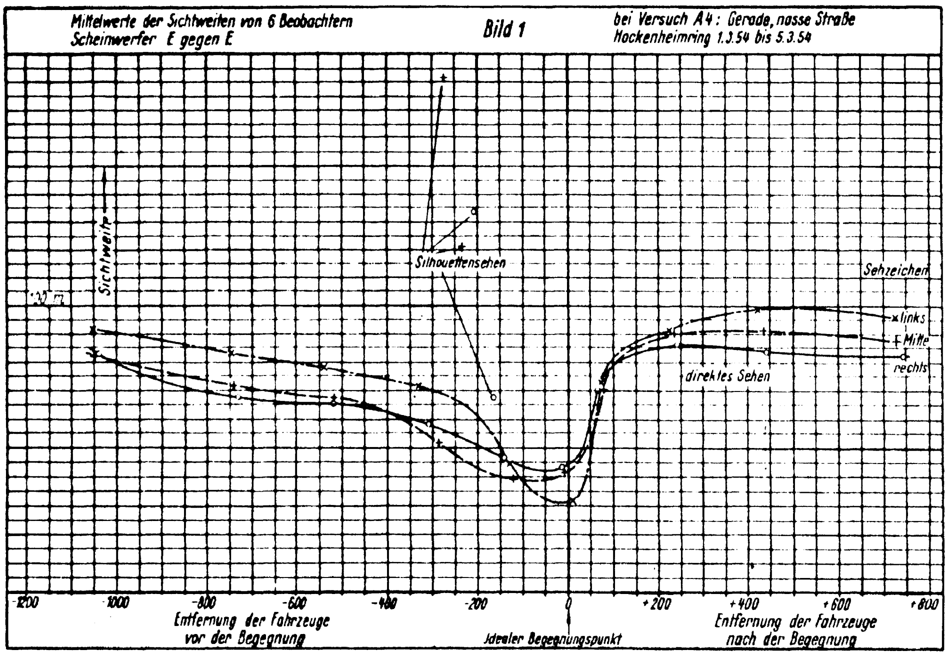


Figure 4. Visibility Distances Measured to Targets Placed on Left, Middle and Right of the Road for European Lamps Meeting European Lamps. (From Kazenmaier [1956]).

(Figure shows seeing distance [Sichtweite] before and after the meeting point [Jdealer Begegnungspunkt] for targets on the left [links], middle [Mitte], and right [rechts] of the test vehicle.) Also shown are results for targets seen in silhouette [silhouettensehen].

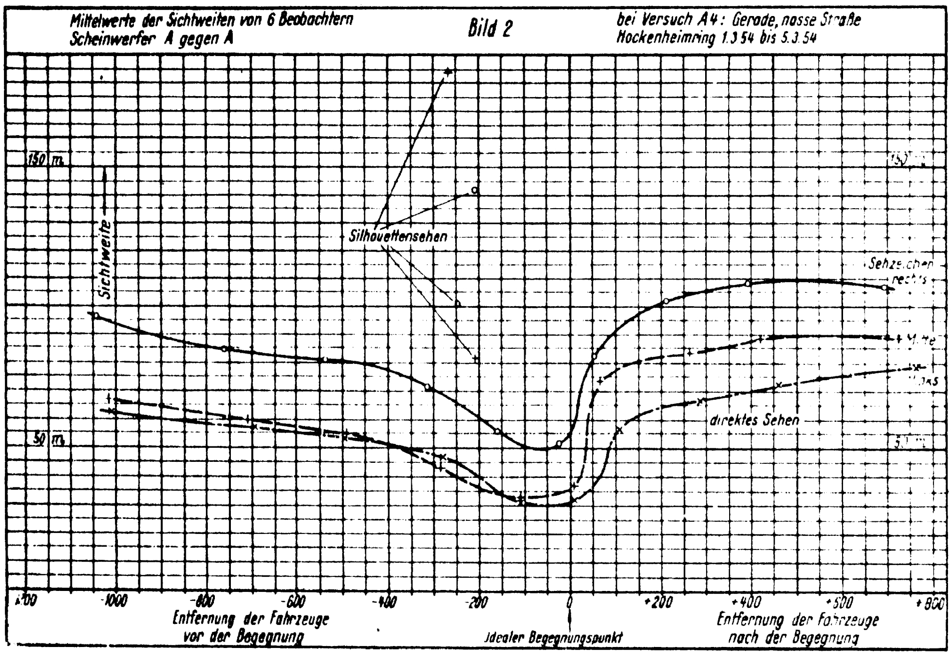


Figure 5. Visibility Distances Measured to Targets Placed on Left, Middle and Right of the Road for American Lamps Meeting American Lamps. (From Kazenmaier [1956]).

(Figure shows seeing distance [Sichtweite] before and after the meeting point [Jdealer Begegnungspunkt] for targets on the left [links], middle [Mitte], and right [rechts] of the test vehicle.) Also shown are results for targets seen in silhouette [silhouettensehen].

One question which the efforts of this commission could not resolve was that of illumination directed into the upper left quadrant of the beam pattern. Obviously, this is the area which provides disability and discomfort glare for the oncoming motorist. European scientists felt then, as they do now, that glare must be minimized, where the Americans felt higher glare levels were acceptable. As a result, the Europeans decided to stay with the shielded filament concept but sought a means which would allow greater illumination to be directed down the right side of the road. This modification has been described by de Boer (1956). The solution was to remove part of the filament shield on one side so that high intensity illumination was directed above the horizontal down the right side of the road. This produced the beam pattern illustrated in Figure 1. Because of the change in the filament shield, it was necessary to modify the lens somewhat. At the same time the bulb mounting was redesigned to insure greater accuracy in filament position. The result of this program was an improved European beam pattern which was, in the opinion of European engineers, capable of equalling the visibility distance afforded by the American sealed beam to all areas of the road environment.

In the early 1950's scientists at the Road Research Laboratory in Great Britain developed a computational technique for determining headlamp seeing distances based on beam intensity and glare. This has been used in a number of applications. One of the most interesting studies, from the point of view of this review, involved a comparison of European and British headlamps on curved roads (Jehu, 1957). The results of some of the calculations provided by Jehu are shown in Table 6. Note that the European lamps are of the older symmetrical type.

The results of this investigation show no clear advantage to either system, since the visibility afforded depends on the distance between the target object and the glare source, and whether the target is on the right or left side of the road. However, Jehu felt

TABLE 6. Comparison of Calculated Seeing Distances for British and European Headlamps. (From Jehu [1957]).

Object position	Distance between object and glare source (ft.)	Seeing distances with the following opposing beams: Double Lamps — Modern British versus Modern British (ft.)	Double Lamps — European versus European (ft.)
Nearside Object	+ 500	196	175
	+ 300	191	174
	+ 200	175	172
	+ 150	158	170
	+ 100	142	164
	+ 50	137	157
	0	134	145
	- 50	137	139
	- 100	153	152
Object in centre of road	+ 500	173	152
	+ 300	155	150
	+ 200	89	139
	+ 150	71	118
	+ 100	63	89
	+ 50	58	80
	0	73	82
	- 50	102	105
	- 100	136	--
Offside object	+ 500	136	112
	+ 300	60	< 50
	+ 200	50	< 50
	+ 150	50	< 50

that the advantage lay with the British system, which was almost always better than the European in revealing the important near-side object. (For Americans, "near side" corresponds to the right side of the road.) Recall however, that this test involved the earlier symmetrical European beam. The results probably would have been more similar were an asymmetrical European beam used instead.

Lindae (1962) has reported the results of tests comparing U.S. two- and four-lamp sealed beam systems with the European asymmetrical system. These results are summarized in two figures taken from his report. Figure 6 shows the results for targets on the right hand side of the road. The differences between the two systems appear minimal. Figure 7 shows the results for targets placed on the left side of the road. In this instance there is a substantial difference, with the European system producing about a 30% increase in visibility distance under no glare conditions and more than a 50% improvement under glare conditions.

The study described by Lindae is one of the few which reports substantial differences in seeing distance comparing U.S. and European systems. Insufficient information is provided by the author to make it possible to determine why the observed differences came about.

The Psychological group at Uppsala in Sweden have reported several studies dealing with various problems in night visibility. The first comprehensive investigation of different types of head-lighting to come from that group was reported by Johansson et al. in 1963.

Five studies were carried out. They included comparisons between high and low beams, symmetrical and asymmetrical headlamps, and different target reflectivities. The investigators used a semi-dynamic technique which was different from that usually employed.

The criterion was the distance to a target at the moment it could no longer be seen by the subjects. The authors argue that

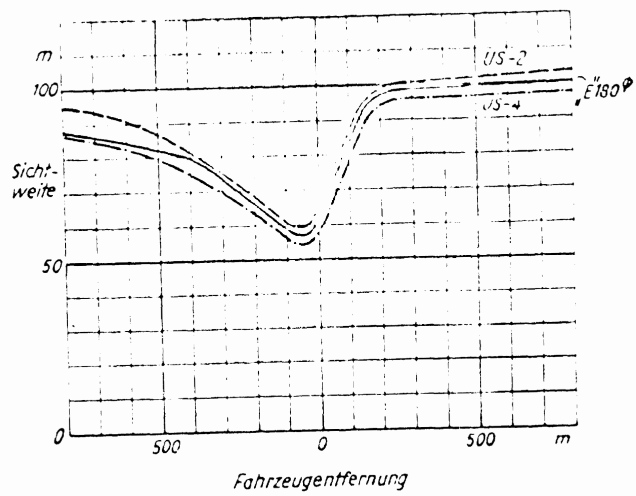


Figure 6. Seeing Distances Provided by European and American Headlight Systems for Targets on the Right Side of the Road. (From Lindae [1962])

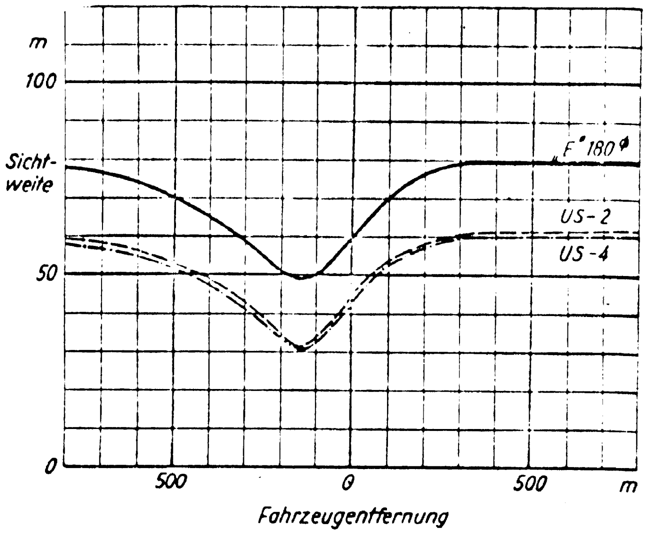


Figure 7. Seeing Distances Provided by European and American Headlight Systems for Targets on the Left Side of the Road. (From Lindae [1962])

this is a better way of assessing visibility distance than trying to measure the first moment that a target can be detected. The subjects were seated in a motor vehicle which was static throughout the study. A glare car was positioned ahead of them on the road. The subjects were asked to indicate the furthest targets that could be discerned without the headlights of the galre vehicle being on. The glare vehicle headlights were then switched on and a new set of measures were taken. The glare vehicle then accelerated and drove toward the subject vehicle, the subjects being required to indicate the most distant target which they could discern as the glare vehicle approached.

The technique employed by Johansson et al. corresponds to what psychologists call a "descending format" when studying human behavior. The typical approach to headlighting experiments uses what is called an "ascending format." The rationale for using a descending format is that variance associated with the "surprise" appearance of a target is minimized. This makes it easier to distinguish between various test conditions. The present author is doubtful that this is a valid argument. The major variance in a study of this type is associated with the level of confidence at which a subject will respond. This problem is no different for descending than for ascending format. Further, the use of a descending format will result in significantly longer visibility distances, which make it more difficult to compare these results with others.

Certain results of the Johansson et al. study would have been expected. For example, detection distances increased as target reflectivity increased. It was also found that visibility for objects on the near side of the road (right side in U.S.) were greater with an asymmetrical than with a symmetrical low beam. Results concerning visibility with high beams were somewhat surprising. These data indicate that high beams versus high beams gave longer visibility distances throughout the meeting situation than did low beams meeting low beams. The measured visibility distances for low beams were about 25 meters maximum, 20 meters minimum. For the high beams, visibility distances varied from about 55 meters maximum to about 25 meters minimum. These results differ from those reported by other investigators and may be attributable to the different methodology employed.

Tests comparing the British headlighting system commonly used in the early 1960's with the asymmetrical European system of the same era have been reported by Fosberry and Moore (1963). The results were gathered using semi-dynamic tests similar to those used by Harris (1954), described earlier. The target was a board 18 inches high, having 7% reflectivity. Seeing distances for objects on the near side (right side for U.S. use) were quite similar for all units tested. The seeing distances to objects in the center of the road were quite comparable as well. The authors note: "with such very different beams, it is indeed surprising that, in terms of seeing distances, differences are only marginal."

One of the first tests of visibility distance provided by quartz halogen European lamps compared to American sealed beams has been reported by Roper and Meese (1965). These tests were conducted using two vehicles, both of which were in motion at speeds of 40 mph. Targets consisted of 16" squares having 7% reflectivity set on the right side of the road. Subjects were instructed to indicate when they had detected the presence of a target by pushing a button. Figure 8 shows the results of this test. Relatively little difference was found between the two systems, perhaps 10% at maximum. However, the U.S. lamp was consistently better than the European except at the maximum glare point.

In a study of the interaction of headlamps and fixed lighting, Faulkner and Older (1967) investigated various lighting conditions including British and European style low beams. The authors do not specify whether conventional tungsten or quartz halogen sources were used in their European lamps. It is clear that the asymmetrical European pattern was employed. The target used in this study was

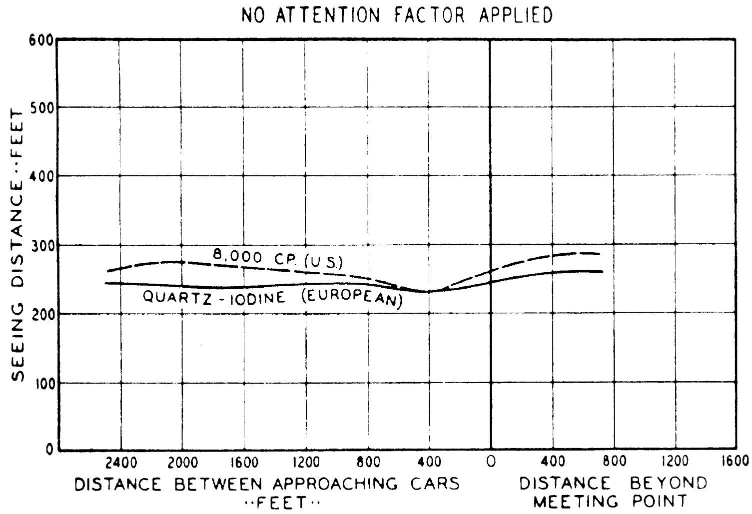


Figure 8. Seeing Distances to Targets on the Right Side of the Road Provided by American and European Low Beams. (From Roper and Meese [1965])

unusual. It was four feet high, rectangular in shape and had on the top a circular portion with a projection on one side. The projection could be moved to various positions. The task given the subjects was two-fold. First they had to detect the presence of the target itself, and second they had to identify the orientation of the projection. The results are reported in terms of detection and identification distances. The target could be placed in any of six positions, ranging from 400 feet in front of the glare source to about 300 feet behind it. All runs were made facing identical headlamps.

The results indicate that the European beam produced generally greater detection distances than did the British low beam. These differences were greatest when the target was positioned just in front of and just behind the glare vehicle.

The recognition distance data are different. In the first place, the recognition distances are about one-fifth as long as the detection distances. It was also found that the recognition distances were substantially greater for the British low beam when the target was positioned in front of the glare vehicle and somewhat greater for the European low beam when the target was positioned behind the glare vehicle.

The study by Faulkner and Older raises an interesting question about the criteria employed in headlighting studies. As was noted earlier, detection distance is the usual way in which headlight performance is measured. However, simply detecting an object may not be enough. It is also necessary for the driver to identify an object sufficiently well to determine whether it constitutes a problem or or not. The extent to which this identification-decision process can be simulated in an artificial experiment is questionable. It remains one of the unresolved (and largely unexplored) issues in headlighting research.

The first experimental comparison between conventional tungsten and quartz halogen European beams was reported by Rumar (1970). This study was carried out using a semi-dynamic procedure. A static glare car was employed, with the subjects being driven down a two-lane road toward the glare car. A target detection criterion was used. The subjects were required to press a button when they detected relatively small, 4% reflectance targets placed along the right edge of the road. The results indicated that the new halogen lamps on high beam produced about a 25% improvement in visibility distance. When meeting other cars with low beams the halogen lamp was still superior to the conventional tungsten lamp.

In a general article concerning problems of night visibility, Christie and Moore (1970) make reference to experiments carried out at the Road Research Laboratory in Great Britain comparing the relative merits of European and British style low beams. In an apparent reference to the work of Faulkner and Older mentioned earlier, Christie and Moore claim that the European quartz halogen headlamp is to be preferred for all conditions of roadway lighting, <u>if</u> good aiming can be insured. This is an important if. The authors recognize that there are substantial difficulties in maintaining headlamp aim under all driving conditions. The paper goes on to discuss various ways of improving headlight aim, including devices which compensate automatically for changes in vehicle attitude.

The Southwest Research Institute has conducted a number of headlighting studies. Their purpose was to measure the performance of present day lighting systems and recommend improvements. This work has been summarized by Hull, et al. (1971). Among the systems investigated were American sealed beams and European quartz halogen units. The conditions under which the tests were conducted consisted of two cars on a straight, flat road with both experimental and glare cars in motion. The results, for a 7% reflectance, pedestrian size target set on the right edge of the road, are summarized in Table 7.

The high beam comparisons are not surprising, given the fact that there is a substantial intensity difference between the two systems.

TABLE 7. Visibility Distances Measured for Two Headlamp Systems Based on Tests Carried Out at Southwest Research Institute. (From Hull, et al. [1971])

Test Conditions	Low Beams		High Beams	
	U.S.	European	U.S.	European
Facing Glare Car with Identical Lamps	362	356	328	428
Unopposed	434	417	811	1,023

Distances are in feet.

The comparison between the low beams indicates that, for the conditions tested, seeing distance differences are minor.

One of the most interesting reports in recent years comparing American and European headlighting is by Rumar, et al. (1973). This was a semi-dynamic simulation in which the subjects rode in a car which was driven toward a stationary glare vehicle positioned in the center of the left lane. The distance at which the subjects could detect dark obstacles placed along the right edge of the road was measured. For no-glare situations, the results indicate that the European high beam provided approximately 15% more visibility distance to the test object on straight roads, while on sharp cruves differences between the European and American high beams are negligible. For low beams, the results indicate that on straight roads the American low beam provided substantially greater glare and, as a consequence, somewhat less seeing distance (about 10%) than the European beam. It was also found that the American low beam provided an even greater percentage increase in visibility as target reflectivity was increased. On curved roads the two low beam systems gave roughly the same performance, except for sharp curves to the left, where the American low beam provided somewhat better visibility.

This report, coming from an organization which has done much careful work on headlighting over a period of years, and from a country (Sweden) which uses the European system, has added some fuel to the controversy concerning European and American beam patterns. The results seem to indicate a substantial superiority for the American low beam. In this respect, the results differ from all other reports comparing European and American headlighting with which this author is familiar. Given this fact, it is appropriate to wonder why, under test conditions which are similar to those used by others and which appear quite reasonable, the European lamp should look so inferior to the American lamp.

Unlike some investigators, the Uppsala group carefully photometered the lamps that were used in their tests and published some of the results in their report. Figures 9 and 10 shows the isocandela diagrams for one each of the European and American low beams used in the tests. It becomes immediately apparent that there were large differences in the output of these lamps in the area in which the target objects would likely be encountered. For some reason the European lamps selected (at least the one which is presented in the figure) had an output close to the minimum prescribed, while the American unit shown had specifications which were at or exceeded the maximum allowed under SAE regulations. Additionally, for some reason, the maximum intensity point of the European unit was oriented more than 3^0 to the right instead of between $1\text{-}2^0$, as indicated in the specifications. The maximum intensity point of the American unit was also aimed somewhat down and to the right relative to the specifications, but the high intensity zone was least near the edge of the roadway.

Assuming the second lamp in each pair was approximately the same as the one for which isocandela diagrams are provided, it is questionable whether the test described by Rumar et al. can be truly characterized as a comparison of American versus European beam patterns. It was more a comparison of different beam intensities.

Ohlon and Zaccherini (1972) have reported a follow-up of the Rumar et al. paper just described. They performed a mathematical analysis of the seeing distance data in an effort to determine why the observed differences came about. The authors accomplished this by analyzing the illumination directed down the road at various heights above the roadway surface and correlated luminous intensity with seeing distance. It was found that the maximum correlation between these values occurred at a height corresponding approximately to the top of the one meter tall targets used by Rumar et al. The authors conclude that the superiority of the American beam in these tests is attributable to light emitted just below the horizontal. On a basis of these observations the authors recommend a new passing

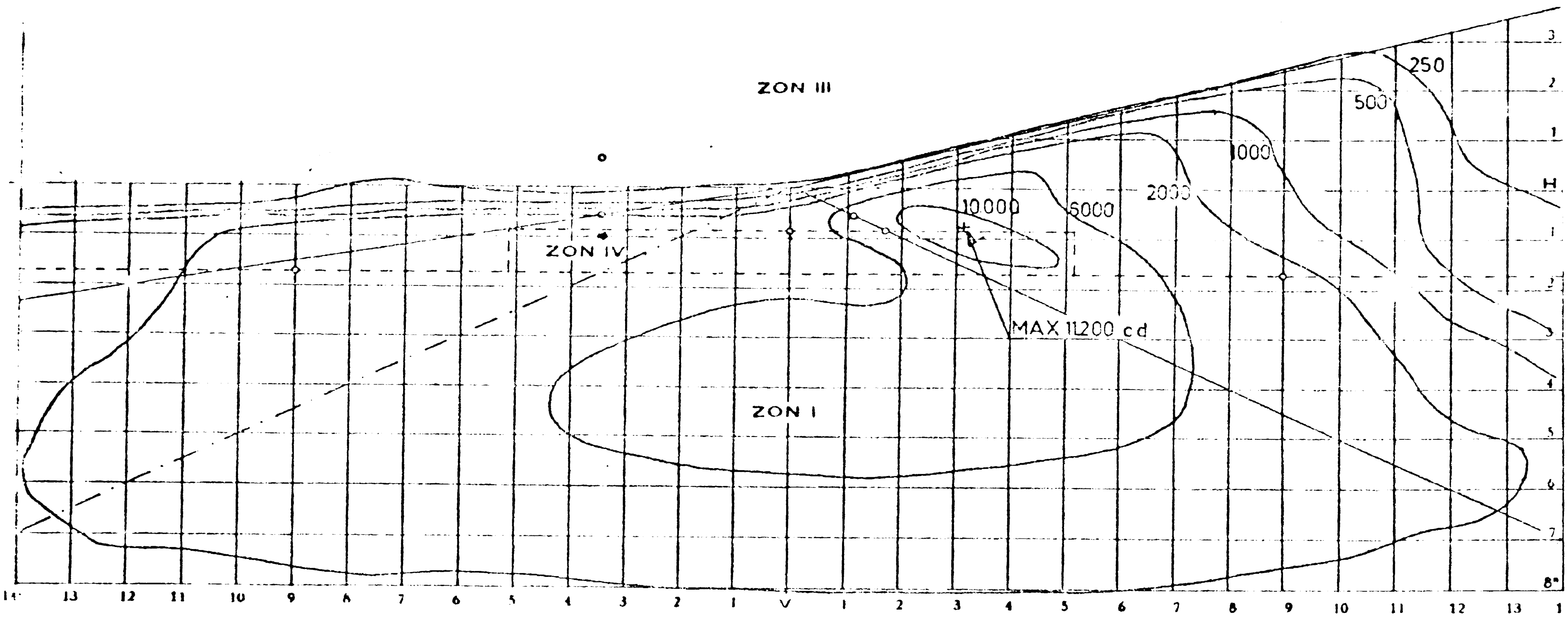


Figure 9. Isocandela Diagram for One European Low Beam Used in Seeing Distance Studies Carried out by Rumar et al. (1973).

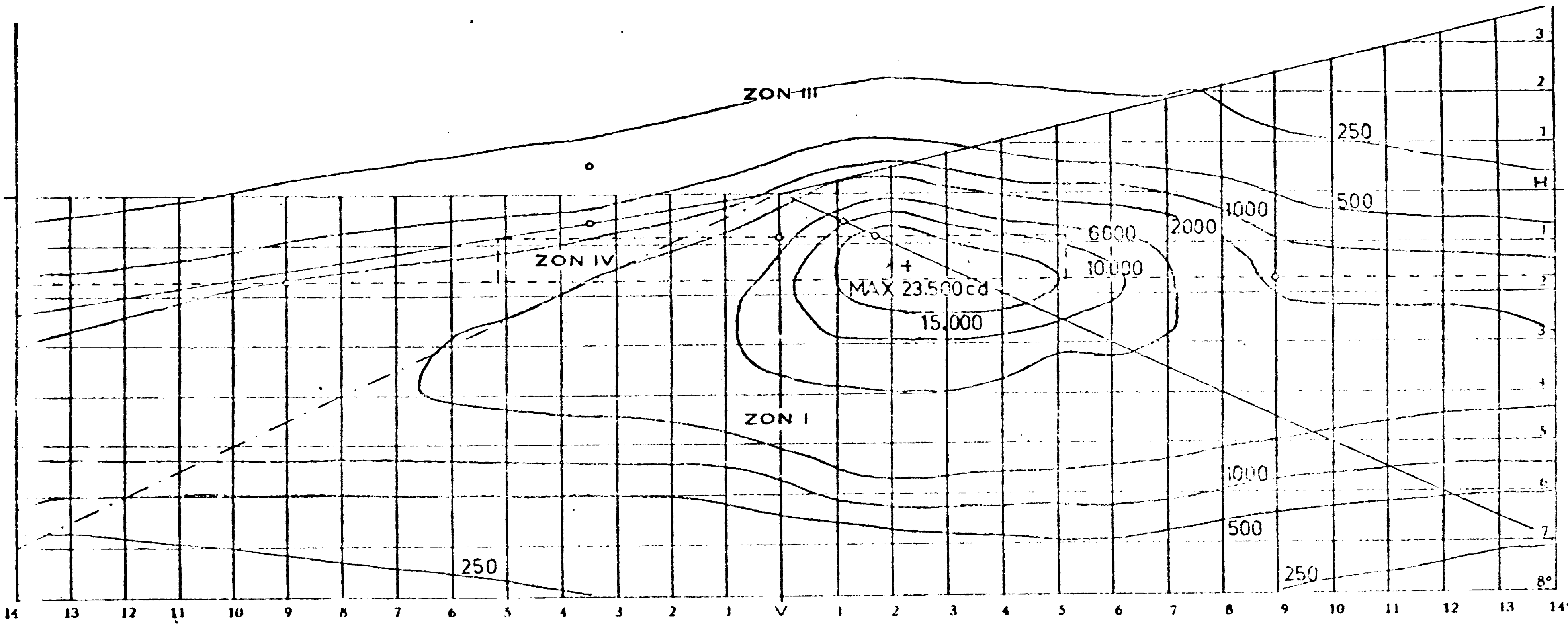


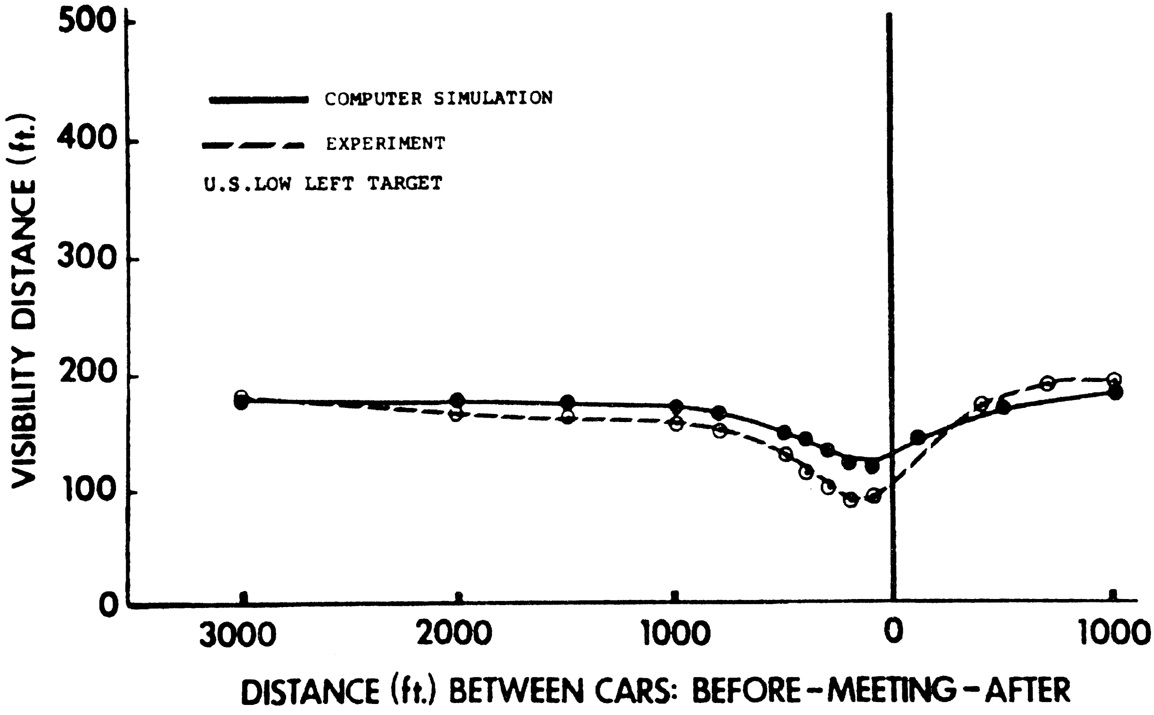
Figure 10. Isocandela Diagram for One American Low Beam Used in Seeing Distance Studies Carried out by Rumar et al. (1973).

beam design. A rough approximation of this may be visualized by taking a typical European low beam and shifting it somewhat to the left.

The headlighting research program carried out at the Highway Safety Research Institute of the University of Michigan was one of the most comprehensive to date. It was divided into three phases. In Phase 1, field test data were collected utilizing fully dynamic simulations. Variables tested included headlamp beam, speed, lateral separation and target reflectivity. These results were used to aid in the development of a computer seeing distance model in Phase 2. In Phase 3, the model was validated by creating new beam patterns and verifying that the model was capable of predicting the visibility distance which they provided.

The targets used in the HSRI tests were different from those used in any other similar program. It posed an identification task to the subjects, rather than simple detection. This was done primarily because pilot testing determined that such a target reduced the experimental variance. No interaction effect of beam and target type was noted, such as reported by Faulkner and Older (1967). The target also had its own background. This had the important benefit of preserving target luminance contrast regardless of the actual environment or position on the road.

As part of the test program, comparisons were run between quartz halogen European lamps and standard U.S. sealed beams. Photometrically, the lamps were more comparable than those utilized by Rumar et al. For example, the U.S. sealed beams had a maximum intensity of 26,000 candelas, at a point 3^0 right and 2^0 down. The European lamps had a maximum intensity of 18,000 candela, at a point 3^0 right and 1^0 down. Thus, while the European lamp had lower output, the high intensity point was located 1^0 higher than the U.S. lamp. The results are shown in Figures 11 and 12 for targets situated on the left and right edge of the roadway respectively. Clearly, the differences between the two systems are minor.



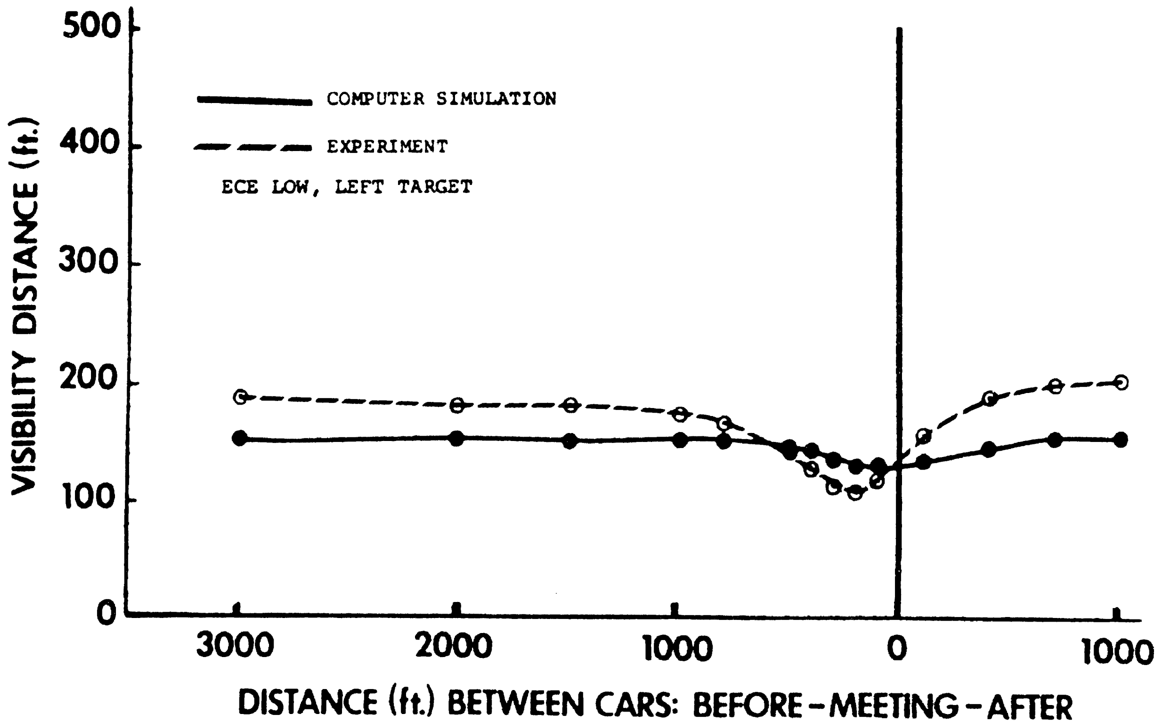


Figure 11. Visibility Distance to Targets on Left Side of Road Provided by American and European Low Beams. (From Mortimer and Olson [1974])

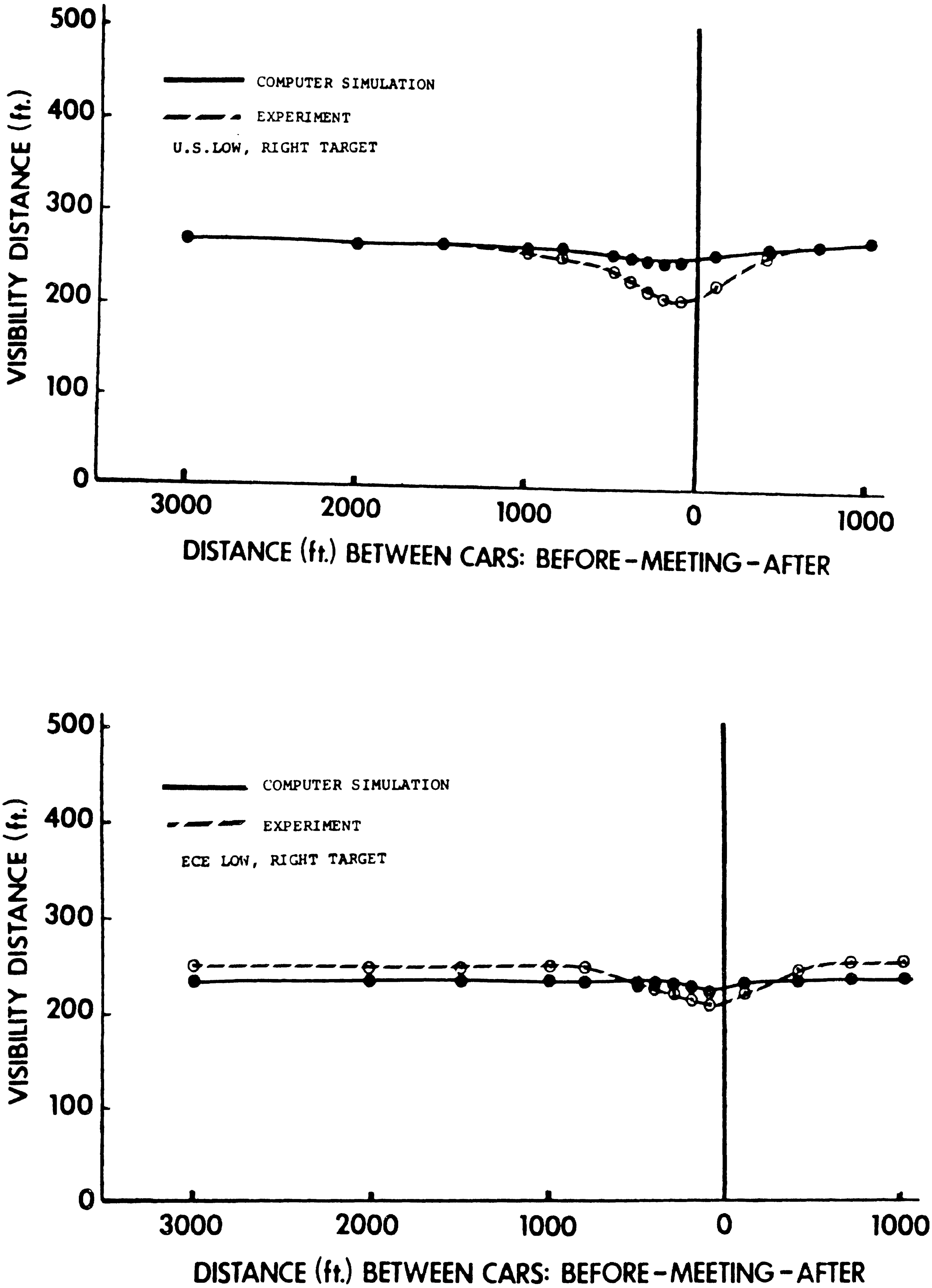


Figure 12. Visibility Distance to Targets on Right Side of Road Provided by American and European Low Beams. (From Mortimer and Olson [1974])

One of the most significant and comprehensive headlighting research efforts in recent years has been carried out at Ford Motor Company (Bhise, et al. 1977). In the first stage of this effort a seeing distance model was developed, somewhat like the one developed at HSRI. The model was validated in a variety of situations to ensure that the visibility distances predicted corresponded to those measured in actual driving situations. A computer simulation of a "standardized test route" was then developed, over which cars could be "driven" with any headlighting system of interest. The test route consists of a series of highway sections in the form of environmental parameters which are thought to have an influence on visual performance and night driving. It includes such factors as pavement, lane line and target reflectance, road geometry, lane configuration, ambient illumination, as well as glare from fixed lighting and traffic. The authors feel that the standardized test route is a representation of a typical American night driving environment. It is based on a series of field surveys which covered thousands of miles of actual highways.

When various headlighting systems are run through the standardized test route, the model outputs a figure of merit. This figure of merit is the percentage of the distance traveled by the simulated driver on the standardized test route in which the seeing distance to pedestrians and pavement lines and the discomfort glare levels experienced by opposing drivers simultaneously meet certain acceptance criteria.

As a final step in the Ford program a large number of different lighting configurations were tested. It was found that the figure of merit output of the model differed very little, indicating that various headlighting systems produce basically the same performance. Among the systems tested were the standard American and European low beam. What the research seems to show is that the driver visual performance on the highway at night is more sensitive to environmental conditions and the driver's visual capability than to the range of characteristics exhibited by existing and proposed headlighting systems. This work suggests that no significant advances in night visibility can be expected through changes in headlighting technology of the usual sort. Only by solutions such as that potentially available through the use of polarization can significant improvements in night visibility be brought about.

As has been noted already, every research effort in the field of vehicle headlighting has relied on seeing distance criteria using subjects who were fully alerted to the nature of the test and the response expected from them. There are two major problems with this approach which have concerned individuals trying to do research in headlighting. One of these problems is fairly obvious. The fully alerted subject will "detect" a given target at a substantially greater distance than would be expected of a person under normal driving conditions. This fact was clearly demonstrated by Roper and Howard (1938), who found that identical targets were detected at twice the distance when the subjects were looking for them as compared with a situation where the subjects were not aware of the fact that there was a target in front of them.

The other problem is a bit more subtle. Little is known about the nature of the information which is required in order to successfully operate a motor vehicle, or the way in which it is secured and utilized. It may well be that there are aspects of headlamp performance which are of consequence but which are overlooked in the traditional headlighting experiment. While these are very real problems, there is no easy way of resolving them.

A promising new approach was attempted recently by the Honeywell Corporation (Graf and Krebs, 1976) under contract to the National Highway Transportation Safety Administration. Honeywell has developed an eye fixation recording device which can be mounted in an automobile and operated so that it is possible to keep the subject unaware of the fact that eye fixations are being recorded. Graf and Krebs used this machine in a study which attempted to measure the detection distance of objects which appeared normal to the roadway environment (roadside junk, mailboxes, signs, man sized dummy). The subjects were not aware of the true purpose of the study. Thus it was thought that eye fixation patterns and detection distances should reflect what happens in the real world. A wide variety of headlighting systems were utilized, including standard American and European low beams.

Graf and Krebs report no significant differences in target detection distance as a function of the various headlighting systems employed. Given the range of patterns and intensities included, this result is unexpected and certainly quite different from the results reported in other studies.

One can only speculate as to why the results turned out the way they did. Of course, one explanation, and the one favored by Graf and Krebs, is that, when measured under realistic conditions, different headlighting systems make very little difference on a task such as this. However, the present author does not believe this to be the case. There are certain aspects of the way in which the study was conducted and the way in which the data were processed which could have led to the finding of no differences. Until such time as the study can be replicated and these questions answered the results can be regarded as only tentative.

Deterioration in Non-Sealed Headlamps

European headlamps, being of composite construction, deteriorate over time. That is, the interior surfaces become dirty and the reflector can pit and corrode. While this characteristic is well known, it would be very useful to have a precise documentation of the rate at which it occurs. The documentation should be in a form useful to owners and public officials, that is, it should relate to photometric performance of the unit.

Although the inevitable decline in performance over time may be one of the most important differences between the U.S. sealed beam and the European lamp, there is remarkably little published documentation. The most comprehensive series of tests seem to have been carried out by the Materials Testing Institute in Sweden. These results have been summarized by Zaccherini (1969). Their data show significant decline in total output and blurring of the beam pattern in a period of less then six months. In other tests, headlamps were mounted in automobiles and run under actual use conditions for periods up to 1.5 years. Declines in output up to about 35% were noted. However, the source of the problem was not identified and no controls in the form of sealed units were used.

Zaccherini expresses preference for the U.S. sealed beam for three reasons:

1. Simplification of aiming.
2. Reduction of deterioration.
3. Standardization to only two types.

Note that the latter advantage has been reduced with the introduction of rectangular units in the last few years.

The Swedish data are interesting but are now nearly ten years old. Some of the results are based on tests with conventional tungsten bulbs, so that bulb blackening is confounded with other sources of deterioration. It would be desirable to develop more up to date information using the most recent headlamps, representative driving conditions and careful photometric analysis.

Summary and Recommendations

This report has provided an overview of vehicle headlighting from a point of view of the different approaches in this country and in Europe. It has examined differences between the two systems in terms of photometrics, construction and, most important, the quality of visibility afforded.

The question now becomes whether it is possible, with this evidence in hand, to decide if one system is superior to the other.

Should one system or the other be required? Is it possible or desirable for both to coexist on the same road system? These questions shall be considered as they relate to photometrics, construction and aiming.

As was noted earlier, headlighting is an area characterized by differences of opinion. The interpretations offered in the following section are those of the author. While no apologies are offered for this fact, the reader should bear in mind that another person might have drawn somewhat different conclusions.

Photometrics: A number of seeing distance studies have been reviewed. The most usual result has been one of little or no difference between the systems. Those studies which report larger differences do not agree on which system is superior. But, as has been noted, the seeing distance studies have examined only part of the problem.

It seems fair to say that there is no agreement as to the "best" low beam configuration. There are a great number of criteria to be considered in the design of low beam units. Inevitably, no one design can be best measured against all criteria. The weighting of criteria is a subjective process at present and seems likely to remain so for the forseeable future. Thus, based on design photometric characteristics, there can be no basis for choosing one system over the other. Nor is there any reason to believe the two systems cannot be successfully mixed on the highways.

From one point of view the photometrics of the European system seem significantly better than the present U.S. system. Thus, for the relatively few individuals who are in a situation which allows frequent use of high beams, there may be a positive benefit associated with switching to European lamps.

Construction. Of far greater concern may be the interaction of construction and photometrics. Being non-sealed, European lamps deteriorate over time, resulting in changes in their photometric characteristics. The present author has a strong bias in favor of safety systems which do not rely on owner maintenance for their effectiveness. In this respect the sealed beam has an edge. The question is: how quickly do European lamps deteriorate under various conditions? Also, how reliable are their owners in replacing units when they do deteriorate? The data here are even less adequate than those concerning seeing distance.

At the present state of the art there appears to be no justification for prohibiting individuals from acquiring European lighting systems based on the possibility that the units may not be given adequate maintenance or replaced when neccessary.

It does seem desirable that a test program be initiated to investigate the problem of deterioration. Such a program may produce evidence which will convince authorities that composite units should not be used. At the very least the effort will develop data useful to guide vehicle owners and relevant public officials in determining when such units should be replaced.

Aiming. Ability to achieve an accurate aim is probably as important or more important than any other feature of headlighting. In this respect, because they can be aimed mechanically, U.S. sealed beams seem to have an advantage. However, despite this, the available evidence suggests that headlamp aim is typically poor. A survey reported by Olson and Mortimer (1973) found that the quality of aim provided by service outlets was highly variable and often poor. Most of the organizations contacted used mechanical aimers, but it was evident that some didn't know how to use them properly and some were badly out of calibration. While this survey was confined to a single mid-western city where there is no motor vehicle inspection program, it is suggestive that there may be a serious problem in headlamp aim, even with the potential advantage of being able to do it mechanically, Certainly, data collected in California and elsewhere documents the generally poor quality of aim found on vehicles under operational conditions.

Thus, the only data available indicate that U.S. sealed beams are often badly aimed in spite of the mechanical aiming feature. There are no data on aim quality of European lamps to compare with that noted for U.S. lamps. It may be that individuals who pay a premium to obtain European lamps for their cars will exercise more care in having them aimed and being sure they stay aimed. However, this is pure speculation. Unfortunately, so is anything else relative to the quality of aim question as concerns European versus U.S. lamps. On this basis it is hard to see how better aiming can be used as an argument for prohibiting the use of European lamps.

European headlamps constitute an alternative system which is equal to and compatable with the U.S. sealed beam system, based on such evidence as is available. The author can see no rational basis for banning their use in this country at this time.

At the same time, the author does not believe that European lamps should be made standard on cars or that their use should be widely encouraged. The U.S. sealed beam system, especially when a 150,000 cd high beam becomes available, is the better choice for most drivers. This judgment is based largely on the fact that the sealed beam does not deteriorate over time. However, for those persons who wish to choose a different system, the European headlamps are soundly engineered and will provide good performance.

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APPENDIX

ANNOTATED BIBLIOGRAPHY

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This document provides the basic specifications for the H_4 halogen headlamp.

Bailly, F., Cibie, P. and Devaux, P. The Use of Iodine Lamps in Car Headlights. Presentation before the Motor Industry Research Association. December 11, 1962.

This paper presents a basic description of the historical development of the iodine lamp as applied to automobile use. It explains the principle of the iodine cycle and also the technological advances which would be incorporated into the new European headlamps using iodine sources.

Becker, J.M. and Mortimer, R.G. Further Development of a Computer Simulation to Predict the Visibility Distance Provided by Headlamp Beams. Highway Safety Research Institute, the University of Michigan. Report No. UM-HSRI-HF-74-26, November 26, 1974.

This report describes some extensions to a computer simulation program for the evaluation of headlamp beams in terms of visibility and glare. In particular, the effects of glare of headlamps reflected in rearview mirrors, horizontal and vertical road curvature, and a glare discomfort index are incorporated.

Those capabilities are illustrated. A listing of the program and a manual describing its use are included as appendices.

Bhise, V.D., Farber, E.I., Sunby, C.S., Trowell, G.M., Walunas, J.B., and Bernstein, A. Modeling Vision with Headlights in a Systems Context. The Society of Automotive Engineers, Technical Report 770238, 1977.

A headlight evaluation model has been developed which provides a broader and more comprehensive method for characterizing the performance of headlamps than is possible in traditional headlight seeing distance field tests.

The headlamp evaluation model accepts as input the candlepower patterns of the headlamp system being evaluated and provides a measure of driver visual performance based on a large number of simulated seeing distance tests and glare discomfort checks on a standardized test route. The output of the model, termed the figure of merit, is the percentage of the distance traveled by the simulated driver on the standardized test route in which the seeing distance to pedestrians and pavement lines and the discomfort and glare levels experienced by opposing drivers simultaneously meet certain acceptance criteria.

A standardized test route is a computer representation of a series of highway sections in the form of a file of enviornmental parameters which have an influence on visual performance and night driving. The simulation includes such parameters as pavement, lane line and pedestrian reflectance, road geometry, lane configuration, ambient illumination and glare from fixed lighting, and traffic and pedestrian density. The standardized test route is a representation of a U.S. night driving environment as measured in a series of field surveys covering thousands of miles of highway and as reported in the literature.

The seeing distance calculations were performed by an integral seeing distance model which is based on the human visual performance literature and validated by field studies. Response to glare is based on published discomfort glare formulations modified and validated on the basis of highway tests.

Applications of the model have shown that driver visual performance at night is more sensitive to environmental conditions and to the driver's visual capabilities than to the range of characteristics exhibited by existing and proposed headlighting systems. This is partly because large increases in candlepower are required to provide useful increases in visibility, and because such increases in candlepower produce a concomitant increase in glare discomfort. Other applications include comparison of several European and mid-beam systems with current U.S. systems, evaluation of headlamp misaim effects and a determination of the effectiveness of improving the brightness of pavement lines.

Bhise, V.D., McMahan, P.B., and Farber, E.I. Predicting Target Detection Distance with Headlights. Paper presented at the annual meeting of the Transportation and Research Board, Washington, D.C., January 1976.

This paper does not provide comparisons of European and American beams. It does, however, provide a very valuable background on the Ford target detection model.

This paper presents results of field research conducted to study the applicability of the laboratory threshold visibility data in predicting seeing distances to stand up and road surface targets while driving under various headlight beam patterns. An instrumented vehicle equipped with a precision odometer system was used to measure detection distance of 12 subjects under different target background glare conditions. The subject testing was followed with extensive photometry to measure the target background and veiling brightness of each target condition. The reflectance properties of the pavement and road shoulder were also mapped in detail. Two different models were used to predict seeing distances. The first, the Blackwell model, predicts seeing distances on a basis of the photometry brightness data. The second, the Ford model, predicted the seeing distances from the candle power distribution of headlamps, reflectance properties of the target and background materials in the ambient road conditions. A comparison of field observed and predicted seeing distances using both models showed excellent agreement. The necessary contrast multipliers needed to account for factors such as, complexity of road surface delineation, transient adaptation, etc. are also discussed.

Christie, A.W. and Moore, R.L. Some Current Views in the United Kingdom of Problems of Night Visibility. Tenth International Study Week in Traffic and Safety Engineering. Rotterdam, September 1970.

This is a very general article about problems of night visibility, particularly the interaction of automobile headlights and fixed roadway lighting. There is, however, a brief discussion of types of headlights beginning on page 3 and there is a brief mention or reference to work carried out at the Road Research Laboratory comparing European and American beam patterns. A statement is made that the advantage lies with the European type beam on lighted as well as on unlighted roads, providing that good aiming can be ensured.

Cibie, P. Summary of Present Day Automobile Lighting. Automotive Electrical Equipment. Proceedings of a conference arranged by the Automotive Division of the Institution of Mechanical Engineers, September 1972, 38-44.

This is a very brief description of the differences between American and European style headlamps. The bulk of the paper is actually devoted to means for automatically making vertical adjustments to headlamps and to steering the headlamps when cornering.

de Boer, J.B. A "Duplo" Headlight with Asymmetric Passing Beam. Light and Lighting, Vol. XLVIII, No. 4, 1955.

This article describes the rationale for development of the asymmetric European meeting beam. Also included are the results of dynamic meeting tests conducted comparing European and American sealed beams. These results are shown graphically in terms of visibility as a function of separation distance for the two beam patterns. The conclusions are as follows:

The results of the experiment show that the asymmetric European beam described produces a visibility which, for objects along the right hand verge, is at least equivalent to, and for objects along the left of the road and along the left hand verge is appreciably more favorable than that produced by the new sealed beam lamps. A comparison of light distribution curves between the two sorts of head lamps shows that the asymmetric European headlight causes, on a straight road, less than one half the glare produced by the new sealed beam lamps. In a transitional period during which symmetrical and asymmetrical passing beams would occur on the same road, the asymmetrical European passing beam can therefore better be endured by drivers using the symmetrical and European passing beams than a passing beam of the Anglo-American type. The asymmetrical European headlamp shows a distinct cutoff on the left half of the passing beam and this is a practical aid in the correct aiming of the headlamp.

de Boer, J. The "Duplo" Car Headlamp Beam with an Asymmetric Dipped Beam. Philips Technical Review. Vol. 16, No. 12, June 1955, 351-352.

This article consists of a brief description of the modifications to the European lighting system which resulted in the asymmetric dipped beam, which projects a greater amount of light down the right side of the road than did the old symmetric beam.

de Boer, J.B. Progess in Automobile Lighting as a Result of International Visibility Tests. Road Safety and Traffic Review. Winter, 1956, 18-23.

This is a very basic and very important article detailing the development of the European headlighting concept. It describes a series of tests which were carried out comparing the then current designs of European and American headlamps. At that time, the

European beam featured the sharp cut-off as it does today, but was symmetrical in appearance. A series of tests were carried out in which seeing distance tests were measured for objects on both the right and the left side of the road. Subjective tests of visibility and glare were conducted as well. The seeing distance tests showed that visibility for objects on the right side of the road was appreciably better for the American beam, where they were better for the European beam on the left side of the road. The subjective impressions gained by the participants in the test was that the Anglo-American beam was to be preferred. This is surprising in view of the fact that the participants were almost certainly people used to the European beam.

The next section of the article describes the rationale behind the new asymmetrical beam developed as a consequence of these tests. The author stresses the need to minimize glare and gives a number of reasons for doing so. He also mentions the desirability of having a sharp cut-off, not only to reduce glare but to make it easier to aim the lamp. The rest of the article is devoted to description of the philosophy and technical considerations required in the development of the new Duplo lamp, which has an asymmetrical appearance to provide better visibility on the near side and still allows for very little upward light scatter.

de Boer, J.B. and Morass, W. Berechnung der Sehweite aus der Lichtverteilung von Automobilscheinwerfern. Lichttechnik, Sonderdruck aus 8 (1956), Heft 10, Seiten 433 bis 437.

This article describes some static seeing distance tests conducted in order to verify analytical techniques or calculating seeing distances. The article shows comparisons between calculated seeing distances and field tests comparing an American and European style beam. Note that the field studies were not conducted by the authors of this paper. The following is an English translation of the summary of the paper:

The introduction is a short description of the experiment conducted so far in order to estimate the visibility distances in night traffic. The visibility distances are determined primarily by the headlight intensity, illumination intensity of the objects, and the position of the objects in respect to the vehicle. The relation between these parameters has been established in field runs. The results are shown in tables and partly in graphs. On the basis of these results, it is possible to calculate the visibility distances from the distribution diagrams of rays of lights. In this way, it's possible in a simple manner to compare the quality of various beams.

Devaux, P. Unified European Passing Beam and Yellow Light. Institute of Road Safety and Traffic Research. 4:33, Autumn 1956, 33-38.

This is a very enthusiastic article describing the virtues of the revised European passing beam pattern. This is the asymmetrical development which includes a 15^{0} upslant on the right side to provide greater right edge visibility. The bulk of the article is given over to various technical discussions concerning the value of the system but the thrust of the article is entirely favorable to the European lighting concept.

Dinkel, J. All About Headlights. Road and Track. May 1973, 108-113.

This is an article intended for popular consumption which compares European and American headlighting. There is also a major section on polarizing. The article is generally critical of American beam patterns, at least initially, although it ends up suggesting that if a choice were to be made, the author would prefer a compromise between American and European styles.

Farber, E. and Bhise, V. Development of an Empirical Headlight-Night Vision Model. Paper read at the Driver Visual Needs in Night Driving Symposium of the Transportaion Research Board. September 1974.

This is a very comprehensive description of the Ford headlighting work. It contains the basic paradigm being explored. It contains a great deal of data illustrating the development and background of the model. It shows comparisons between calculated visibility distances using the Ford model and measured visibility distances as reported by several NHTSA contracters.

Faulkner, C.R. and Older, S.J. The Effects of Different Systems of Vehicle Lighting on a Driver's Ability to see Dark Objects in Well Lit Streets. Road Research Laboratory. RRL Report LR113, 1967.

A comparison is made of the effects on the visibility of otherwise unlit objects of four types of vehicle lighting used by drivers in lighted streets. Observers were driven at 30 mph in a car along a straight well-lit track toward a stationary opposing vehicle showing the same type of lighting. A four foot high target was placed at various positions on the track between 400 feet ahead of and 300 feet behind the opposing lights. The distances were measured at which each of six observers positively detected the target and recognized the orientation of a small projection on top of the target. At least three runs were made for each of the target positions studied.

Detection and recognition of targets on the near side of the observer were unaffected by the type of vehicle lighting. A zone was found on the off side of the observer, near and beyond the position of the opposing car, in which both detection and recognition of the target were impaired when normal low beam headlamps were used compared with the situation in which side lights, low intensity low beam headlamps, or European beam headlamps were used. The latter types of lighting all gave similar results. The differences between lighting systems were common to all observers.

Fisher, A.J. A Review of Vehicle Headlighting Practice. Institute of Highway and Traffic Research, University of New South Wales, Australia. Australia Road Research Board, Project 1022/HE/2, Report No. 6, June 1968.

This is an excellent, in-depth summary of the general problem of headlighting, with some reference to differences in philosophy in headlight beam comparing European and American beams. There is a very comprehensive discussion beginning on page 28 of the report.

Section 8.8 of the discussion summarizes the American/European lighting concept as follows:

"Two schools of headlamp design have grown up, the American-British and European, with two and four lamp variations of each. In the former the emphasis is on illumination and in the latter, on comfort. However, the seeing distances in a two vehicle meeting on a straight level narrow road from both kinds of lamps is much the same. Slight misaim effects each about equally. On this basis the choice appears to be difficult but if one type of design is in predominant use, as in Australia (American British), there is no need to choose."

Fisher, A.J. The Directional Intensities from Headlamp Lower Beams. Australian Road Research Board, Project 1022/HE/2, Report No. 9, October 1969.

This is primarily a photometric study comparing various lamps of European and American manufacture. The article contains detailed specifications of then-current lamps as well as a series of photometric tests. It was concluded that the committee would recommend that Australian specifications should be modeled on the SAE specification. It is felt that this would encourage the exploitation of the quartz halogen source in the European type beam rather than in the American type beam, because large increases in illuminating intensities without exceeding permissable clear values would be possible with the European type of lamp. However, the increases in seeing distances would be small, based on experimental evidence mentioned by reference in this report.

Fosberry, R.A.C. and Moore, R.L. Vision from the Driver's Seat. Paper presented to the Conference on Technical Inspection of Motor Vehicles, Brussels, September 1963.

The bulk of this paper is concerned with general vision problems to the front and rear as determined by vehicle architecture. There is a brief review of vision work as a function of headlighting carried out at the Road Research Laboratory and on page 39 there are seeing distance curves comparing asymmetric European and British style sealed beam lamps. The comment is made "with such very different beams it is indeed surprising that, in terms of seeing distances, differences are only marginal." This is followed by a section on the effect of misaim. A paper by Harris is quoted which compares misaim as a function of the sharpness of lamp cut-off and demonstrates that for longer seeing distances very sharp cut-offs are highly beneficial. These figures are reproduced on page 41 of the report.

Given, K. A Low Beam Look at Headlights. Motor Trend. July 1972, 33-34.

This is an article which is highly critical of the American sealed beam concept without being very specific. The author is obviously impressed with European style lamps but seems to confuse bulb technology with lamp performance.

Graf, C.P. and Krebs, M.J. Headlight Factors and Nighttime Vision. Honeywell, Inc., Systems and Research Center. April 1976.

This study examined the feasibility of using information concerning driver scan pattern data in the analysis of headlamp effectiveness. The driver-subjects were unaware that their eye movements were being recorded. In Experiment I, eighteen subjects drove over rural two-lane roads with indigenous targets under daytime conditions and at night with six headlight configurations. The major independent variables included headlamp type, target type and reflectivity, road geometry, and glare versus no-glare. Dependent measures were average dwell point, scan pattern distribution, and target detection distance. Results: 1) Scan pattern differences were found among headlights. 2) Nighttime scan patterns differed from daytime patterns. 3) Scan patterns on right and left curves were different for different headlights. 4) Scan patterns were relatively stable over time for a given headlamp. 5) Glare from an opposing car altered scan patterns toward the glare source. 6) No significant differences in target detection distance were found among headlights. 7) Target size and reflectivity greatly influenced detection distance. 8) Vehicle parameters (velocity, steering, and braking responses) were not nearly as sensitive to lighting differences as was eye data. 9) The scan pattern of the alerted driver is markedly different from that of the unalerted driver. In Experiment II, target detection distances were obtained for 22 subjects under unalerted and then alerted conditions.

Harris, A.J. The Meeting Beams of Headlights; Effects of Deterioration and Misaim. Transactions of the Illumination Engineering Society, London, 18(8), 1953, 207-220.

The most important factor in the design of the typical meeting beam of headlights, so far as the range of direct seeing is concerned, is the sharpness and form of the cutoff near the horizontal. But the effect which the cutoff will have on the likelihood of being dazzled, in other words of being rendered incapable of seeing more then a short distance when meeting other vehicles at night, depends enormously on the accuracy with which meeting beams are aimed. The effect can be calculated when the standard of aiming is known. The basis of the calculation and some results are given in this paper. Curves are provided from which may be found a sharpness of cutoff required to give any desired level of freedom from dazzle. It is shown that if a standard of aiming is too low, it will be impossible to design a beam to fulfill the required conditions. The necessary improvement in aiming can, however, be determined from the curves. The effect of deterioration in increasing the liability to dazzle is also considered. The pitching motion of the vehicle and its effect on seeing distance and on intermittent glare have had to be omitted from this analysis. The effect will be more important, the sharper the cutoff employed.

Harris, A.J. Vehicle Headlighting: Visibility and Glare. Road Reasearch Laboratory, Great Britain, Technical Paper No. 32, 1954.

This is a very comprehensive report. Although dealing with beams which are now 25 years out-of-date, it contains a great deal of information on tests and computations which were run at that time comparing the Anglo-American and European beams. Contained in the report is a general introductory section on the effect of glare, some results of seeing distance tests, a section on the condition of headlamps on existing vehicles, another section of the effect of load on aim, a section dealing with the effect of misaim on the performance of a meeting beam and results and calculations pertaining to the design of the meeting beam. Included in the latter section are some theoretical results showing the effect of sharpness of cutoff on seeing distance. These curves, which are reproduced beginning on page 23 of the report, indicate that the sharper the cutoff the more effective the lamp at revealing targets at great distances.

Harrison, A.L. Measured Illumination Characteristics of the 1975 Headlamps. National Research Council of Canada, Laboratory Technical Report, LTR-STE .845. March 1976.

This report contains isocandela maps for a large selection of European and American headlamps on both high and low beams.

Helmers, G. and Rumar, K. High Beam Intensity and Obstacle Visibility. Department of Psychology, University of Uppsala, Sweden. Report No. 150, 1974.

The main concern of this paper is problems in visibility created by a substantial range of beam intensities. The authors point out that in Sweden there are no upper limits on beam intensity. This produces a situation where there may be substantial variance among vehicles in the type and intensity of high beams that they employ. The experiment used a standarized visibility procedure developed by this group. The subjects were seated in a stationary vehicle and an experimental vehicle was driven toward them. Following is the abstract:

Visibility distances to obstacles on the right hand side of a straight two lane road have been obtained for the following situations:

a. High beam of varying intensity with opposing low beam of about the same intensity.

b. High beam of varying intensity with lower intensity levels in the opposing high beam.

c. Low beam with opposing low beam.

d. High beam without opposing glare.

Results are summarized as follows:

1. High beam with opposing high beam of about the same intensity: there are no significant differences in the visibility distance as a function of high beam intensity over about 50,000 candela.

2. In high beam with opposing high beam of about three times the intensity or more, there is a large loss in visibility distance (greater than 35%) compared with the situation with identical intensity.

3. The optimal distance between two approaching vehicles for

switching from hiah to low beams increased by about 250 meters when high beam of one of the two oncoming vehicles is increased from identical intensity to twice the intensity of the first vehicle. The optimal distance for switching from high to low beam varied between 250 meters and 400 meters when the two opposing vehicles had about the same high beam intensity.

4. In high beam without opposing glare there is very little gain in visibility in relation to the amount of increase in intensity above 50,000 candela. These results clearly show that the range of high beam intensities on the road should be minimized in order to make the visibility distance in car meetings as long as possible.

Helmers, G., Rumar, K., and Ytterbom, U. Optimering av halvljusets ljusfordelning. (Optimization of the low beam light distribution.) Trafikforskningsgruppen Psykologiska Institutionen, Uppsala Universitet, February 1977.

Several previous studies show that the present low beam system cannot offer visibility distances that are required at the speeds that are normal on our roads. The inefficiency of the low beam is one of the main causes of the large risk in night driving. However, results also show that changes in the low beam light distribution have large effects on the visibility distances offered.

In the present study the first step was to produce headlights with different low beam light distributions. This was carried out by cooperation with headlight manufacturers. The changes and modifications were discussed and suggested by a special expert group on automobile lighting organized within the Swedish Road Safety Administration. The light distributions of these prototypes were measured with special accuracy.

The second step was to study systematically in full scale the luminances and contrasts prevalent at the moment of detection of obstacles, with and without oncoming headlights.

Results from these measurements were then used in the third step where a model for visibility distance calculations was set up.

The predictive performance of this model was tested against the results from field registrations of visibility with those headlights with modified low beam distributions that were judged to be most interesting.

Finally, the model was used for calculations of visibility distances offered by some chosen headlights by driving on a real road with horizontal and vertical curves. Moreover the visibility effects of some special conditions such as curve radius and misaiming were calculated. In this way various headlights can be ranked.

It seems that the model developed offers possibilities to specify and develop improved headlight light distributions.

Hemion, R.H. The Effect of Headlight Glare on Vehicle Control and Detection of Highway Vision Targets. Southwest Research Institute, Project No. 11-1908, Report No. AR-640, May 1968.

Typical night vehicle meetings on unlighted two, three, and four lane highways were simulated. Vision tasks for subject drivers were provided utilizing common highway visual objects as targets. Various vehicle headlighting systems, including standard low and high beam, high intensity and polarized lamps were studied under varied conditions of vehicle speed and separation distances between opposing single and multiple vehicles with respect to the vision targets with drivers having varied glare adaptation response. Measurements were made of detection distance capabilities of the observers and their steering response to targets and oncoming glare vehicles. The following are some of the key findings of the report:

1. Detection distances with normal headlighting were greater when both vehicles were on high beam than when both vehicles were on low beam even though discomfort and visibility glare were greater on the high beam case. Lateral separation was found to markedly improve overall performance and reduced the impression of subjective glare.

2. Test speeds, 30 and 55 mph did not affect results.

The presence of an opposing vehicle in the highway causes the driver to steer toward the road edge. This phenomenon was found to begin to develop 5-7 seconds before the meeting point and increases until the vehicle pass. The amount of lateral displacement occurring during the meeting encounter increases with increasing glare intensity, particularly in the two-lane road case. Meeting a queue of closely following vehicles will reduce detection distances of roadside objects more than a single vehicle because of the greater length of time that glare is present as well as an increase of 20% in glare intensity. The authors conclude with a strong pitch for polarized headlight systems.

Hemion, R.H. Night Visibility Improvement through Headlight Glare Reducition. Southwest Research Institute, Project No. 11-1908, Report No. AR 696, September 1969.

Studies conducted to determine highway visibility and headlight usage during night driving with various lighting configurations are summarized in this report. Means by which night visibility may be improved by use of polarized headlamps or overhead fixed lighting are discussed. It is concluded that existing headlights are unsatisfactory and that polarized light headlights can provide a solution. A public trial of polarization to provide information of the potential benefits and deficiencies is recommended.

This is a very general summary of the early headlighting studies carried out at SWI.

Hemion, R.H. Interchangeability of Vehicle Headlamps. Southwest Research Institute, Report DOT HS-800966, August 30, 1973.

The article considers the problems brought about by the proliferation of different types of headlights. Its primary concern is with the then pending introduction of rectangular headlamps as well as various midbeam headlamps. The article weighs a variety of factors including costs, difficulties of replacement, etc., and concludes that for reasons of styling freedom, the small rectangular headlights should be allowed to be introduced.

Hull, R.W., Hemion, R.H., Cadena, D.G., and Dial, B.C. Vehicle Forward Lighting Performance and Inspection Requirements. Southwest Research Institute, Report AR-814, July 1971.

This project was instituted to study means of improving seeing distance in night driving. Objectives were to determine headlamp system performance requirements, develop procedures for compliance testing and field inspection, and make recommendations for updating the Federal Motor Vehicle Safety Standards 108 covering vehicle lighting. Experimental testing was conducted using new and present standard headlighting systems to determine comparative glare and target detection distances. Lamps used in the field evaluation of lighting systems were photometered, using contractor developed techniques. A total of eight unique systems were evaluated under controlled conditions and glare tolerance by the driving public was investigated on public roads in five geographical areas of the continental United States. From analysis and field tests a three beam system was developed as a proposed short range improvement in vehicle lighting. For long range improvement, a system of polarized lighting was investigated. Commercially available, visual, mechanical and photoelectric equipment for aim inspection was used and evaluated. An effects of vehicle structural detail, loading and other features on aim and retention of aim were investigated. Conclusions and recommendations pertain to motor vehicle standards 108, compliance testing, and further study.

This is the basic summary article of the Southwest Research Institute lighting investigations. The bulk of the report is devoted to exploring the possibilities and results of testing using polarized headlighting. There are, however, detailed summaries of earlier tests conducted, exploring various lighting alternatives including a comparison between European and American headlighting. These results are summarized on tables on page 17 and 18. There is, also, earlier in the report, a very general description of different headlighting systems, the features and photometric requirements thereof.

Jehu, V.J. A Method of Evaluating Seeing Distances on a Curved Road and its Application to Headlight Beams in Current Use. Transaction of the Illuminating Engineering Society, Vol. 22, No. 3, 1957, 69-83.

A method is described by which direct seeing distances can be evaluated when two vehicles meet on a curved road at night. The method is a development of that already used to determine seeing distances from vehicles when they meet on a straight road. It has been applied to three headlighting systems in current use, the modern British beam, the symmetrical European beam and the single lamp meeting beam representing earlier British practice.

Considering meetings on both straight and curved roads, it is shown that in some circumstances the modern British system is better than the symmetrical European system and that in others, the order is reversed. The modern British system is almost always better than the European in revealing the important near side object. Seeing for all object positions is considerably better during the early stages of a meeting on a curved road when the observer is on the inside of the bend. This result is important because the conditions closely resemble those of open road driving with the meeting beam, a frequent occurrence on roads when oncoming vehicles are anticipated.

Taking into consideration also the fact that the modern British system is the less susceptible to vertical misaim, it is concluded that it is the better suited to actual road conditions.

Comparison of the modern double lamp British system with its predecessor, the single lamp system, shows that on narrow roads both straight and curved, the differences between the systems are generally small for all object postions. During the latter stages of the meeting, however, recovery from the minimum seeing distance is considerably more rapid with the single lamps for objects in the driver's own traffic lane.

Jehu, V.J. and Hirst, G. Problem of Headlight Glare. Traffic Engineering and Control, 1962, Vol. 3, No. 9, 545-547.

This article presents calculated seeing distance data for a meeting situation involving low beams and high beams, largely as a function of lateral separation. Some data are also presented for curved roads.

Johansson, G., Bergstörm, S., Jansson, G., Ottanter, C., Rumar, K., and Örnberg, G. Visible Distances in Simulated Night Driving Condtions with Full and Dipped Headlights. Ergonomics, Vol. 6, No. 2, April 1963, 171-179.

Five experiments were reported in which visible distances on the near side of the road were measured in a situation in which two cars met in the dark. Results are as follows:

1. Both cars had full headlights or both had dipped symmetrical headlights: Full headlights were found to give longer visible distances during the whole meeting.

2. The same lighting conditions were compared taking signal reflectance into consideration. The higher the reflectance, the greater the distance.

3. The same lighting conditions were compared in simulated hill meetings situations. Full headlights still gave longer visible distances.

4. Symmetrical and asymmetrical dipped headlights, the type common in Sweden were compared. As a source of glare in a meeting situation they were equal. Although visible distance was considerably longer with the asymmetrical type.

5. Full headlights and asymmetrical dipped headlights were compared. Full headlights gave longer visible distances.

These results indicate that the dipping of headlights, while cutting down the discomfort due to glare when cars meet, also shortens the distances visible from the cars concerned.

This study used as a criterion the distance to a target at the moment it could no longer be seen by the subjects. The authors make quite a point of this being a better criterion than the conventional detection distance. Subjects were seated in a car which remained static throughout the experiment. A series of objects consisting of 145 square millimeter targets were placed along the left edge of the road (this was for a left hand drive situation). At the beginning of each trial, the approach car was stationary at 650 meters in front of the experimental car, but facing along a path corresponding to a traffic lane adjacent to that occupied by the latter. The lights of the experimental car were switched on, while those of the approach car were switched off. The subjects were now instructed to report by means of their switches, which was the furthest object in the series discernable. The approach car now switched on its lights and the subjects again reported the furthest objects discernable. The approach car now started up and accelerated to a speed of 50 kilometers per hour in the first 50 meters. This speed was then held as constant as possible until the approach car had passed the experimental car. During this approach the task of the subjects in the experimental car was to fixate the furthest object which was discernable until it was lost from view due to glare from the lights of the approaching car. They then had to shift their gaze to the next object in the series until this was also lost from view and so on for the whole course of meeting. They were instructed to report shift of gaze by means of their switches.

Johansson, G. and Rumar, K. Available Breaking Distances in Night Driving, the Department of Psychology, University of Uppsala, Sweden, Report No. 13, November 1963.

In some previous investigations in the night driving problems carried out from this department, the relative visibile distances for different conditions were the main interest.

In the experiments reported here, a more realistic method is used and the absolute values are of interest. What is measured is available braking distance (visible distance minus reaction distance). Three conditions were investigated:

1. Two meeting cars, both using continental and European asymmetrically dipped headlights.
2. Two meeting cars, both using full headlights (high beam).
3. One car using continental European asymmetrical dipped headlights with no meeting car.

The results show that for velocities over about 20 to 30 mph, the available braking distance is shorter than the braking distance (distance needed to brake to a full stop) for all conditions tested.

The conclusion drawn is that accidents involving pedestrians, cyclists, etc., in night driving are unavoidable with the car lighting systems and the speeds used at present.

Johansson, G. and Rumar, K. Silhouette Effects in Night Driving. Department of Psychology, University of Uppsala, Sweden, Report No. 19, June 1964.

In order to investigate within what areas on the road silhouettes as framed by the light from a meeting car can be of help to the driver, a series of experiments have been performed.

The experiments employed two stationary meeting cars standing at given distances from each other. These distances, which range from 100 to 400 meters, being determined by pre-experiments. On the area between the cars "iso-silhouette" curves were measured using a special method for a number of silhouette-relevent conditions.

Factors favoring silhouette effects were found to be narrow roads, short distance between the cars, high road surface reflectance, the driver's eyes being high above the road, particles in the atmosphere and large spread of the meeting headlight beams.

Kazenmaier, A. International Vergleichsversuche and Abblendlichtern von Automobilscheinwerfern des americanischen und europäischen Typs. Deutsche Kraftfahrtforschung und Strassenverkehrstechnik. Heft 94, 1956.

The introduction to this report comprises the historical foundation for the completion of international comparative tests between the dim lights of cars of the American and of the European systems. The research program established by the "Working Group Brussels 1952" proved to be so extensive that its completion was distributed amongst the National Committees of Germany, England, France, the Netherlands, and the USA. The report deals then in great detail with the kinetic tests entered upon by the German Committee and concerned with bends of dry roads and with straight of wet roads. The research was carried out by order of the Working Group Brussels by the Light Technical Laboratory of the firm Robert Bosch in spring 1954 on the Hockenheimring and on the Nurburgring respectively. The German Ministry of Traffic granted a research commission for the investigations and partly the means for their completion. The test results are briefly reported also in the final report of the Working Group Brussels. The present report contains furthermore the conclusions drawn from the final report of the Working Group Brussels at Detroit, April 1954, which briefly summarized are: each of the two systems under consideration has advantages as well as disadvantages; consequently the members of the meeting in Detroit could not agree upon recommending one of the two systems as to be accepted as the sole dim light system for all countries. The final report of the Working Group Brussels 1952 was produced at and approved by the Congress of the CIE in Zurich, June 1955, and forwarded through the ISO to the Geneva Authorities of the United Nations.

Kilgour, T.R. Some Results of Cooperative Vehicle Lighting Research. HRB Bulletin, 225, 1960, pages 92-100.

This is a very general article covering a number of topics. There is at the end of the article a detailed history of the development of automotive headlighting up to the time that the article was written.

Linda, P. Headlights for Automobiles. The Society of Automotive Engineers. Technical publication 700087, January 1970.

The first part of this article is a description of general beam types and comparison of European and American concepts. The author seems very much opposed to the European concept. The second part of the article is a highly technical discussion of light sources and reflector design.

Lindae, G. Lincht am Fahrzeug - Ein Beitrag zur Verkehrssicherheit. ATZ Jahrg. 64, Heft 5, Mai 1962, 152-158.

This article is concerned with differences between European and American beams. It contains a general description of the photometric differences and also includes some curves showing the results of tests which were conducted to compare visibility distances for targets on the right and left side. The right side targets appear to have virtually identical seeing diatances, comparing European and

U.S. two and four lamp systems, while there is a difference of about 30% in favor of the European lamps for seeing distances on the left side.

Maurer, P.W., Gioia, A.J., and Oyler, R.W. New Headlight Systems Provide Increased Visibility. Paper read at the Automotive Safety Engineering Seminar. June 20, 1973.

This paper consists of a very general description of the rationale behind the introduction of rectangular headlamps, new advances in lighting (particularly three beam headlighting), and daytime front running lights. It makes no particular mention of European style headlighting, except to plug for the American sealed beam concept.

Meese, G.E. Vehicle Lighting Systems for Two-Lane Rural Highways. Paper read at the Visibility Workshop of the Highway Research Board Visibility committee, July 1972.

This is a general article which provides an introduction to automotive headlighting. It contains an excellent history of the development of automotive headlighting. It contains a very good description of the philosophical reasons for the differences between American and European style headlighting.

Moore, R.L. Headlight Design. Ergonomics, Vol. 1, No. 2, February 1958, 163-176.

This is an excellent if somewhat outdated article describing the evolution of headlights, both of European and American design. It also contains, beginning on page 167, a description of a number of seeing distance studies comparing European and American style headlamps. It should be noted that the European style lamps under test are of the symmetrical type and not of the current asymmetrical type. The article finishes with a description of the principle of polarization and ways in which it might be brought about as well as various problems which impede its implementation.

Mortimer, R.G. The Effect of Glare in Simulated Night Driving. Highway Research Record, No. 70, 1965, 57-62.

Two experiments were carried out in the laboratory in which illumination and glare conditions in night driving were simulated. Steering accuracy was measured as an independent variable. The interactions between roadway illumination, glare illumination, glare duration and glare frequency were investigated.

It was found that there was no differences in performance between the glare illumination levels used in these studies. It was also found that the duration and frequency variables (which reflect traffic speed intensity) required further clarification. Road illumination was clearly important, as well as the overall effect of glare in tracking performance. The presence of higher order interactions showed that the investigation of the glare phenomenon was complex.

It was suggested that the glare hazard and the problems of night visibility could be aleviated by increased reflectance of road surfaces and objects in the road. With respect to the glare source, it was felt that the power of current headlamp units should not be decreased since this would lead to undesirable loss in road illumination. Headlamp units will require further redesign to reduce glare.

Mortimer, R.G. and Becker, J.M. Computer Simulation Evaluation of Current US and European Headlamp Meeting Beams and a Proposed Mid-Beam. The Society of Automotive Engineers, Technical Report 740311, February 1974.

This is an excellent summary paper which compares European and American beams under a variety of conditions, target locations and misaim. Differences between the two systems, as measured by seeing distance, are minor.

Mortimer, R.G. and Olson, P.L. Development and Use of Driving Tests to Evaluate Headlamp Beams. Highway Safety Research Institute, the University of Michigan, Report No. UM-HSRI-HF-74-14, March 1974.

Results of analyses of accident data to evaluate the contributory role of headlighting were inconclusive. Reflectance values of various objects in the driver's field-of-view were measured. Pilot studies were made to evaluate test targets, and the results were used to describe desirable characteristics of a test target for use in subsequent tests.

A series of headlighting field tests were carried out to develop a reliable field test method, evaluate variables affecting visibility provided by headlamps, and generate data for use in validating a mathematical model. Driving tests were also used to evaluate glare effects of various beams to oncoming and preceding drivers.

Three types of targets were developed for the work: a simulated overhead sign, a simulated roadside sign, and a general purpose target to simulate objects on or near the roadway. The latter target could be placed to the right or left of the test vehicle or in the center of its lane of travel. In addition, its reflectivity could be changed.

The following variables were investigated: (1) headlamp beam, (2) lateral separation between vehicles, (3) longitudinal separation between vehicles, (4) target type, (5) target reflectivity, (6) target position relative to car path, and (7) target height.

All of the above variables were found to be significantly related to the distance at which the orientation of the target could be identified.

Targets positioned to the right of the lane are more easily seen than those on the left under glare conditions, and with low beams. Other factors being equal, the closer a target is to the pavement, the more easily it is seen. Retro-reflective targets are seen at far greater distances than painted targets, but very high levels of reflective brillance may actually impede their legibility by making the target itself a glare source.

The test-retest coefficient of reliability of the field test procedure developed in this program is estimated to be 0.97, producing a variation of less than 5% in the visibility distances when the same subjects are retested on the same night. When a different group of subjects, a different test road, headlamps aimed independently on the two occasions, and a stationary glare car in one case and a fully dynamic test in the other case, were used the differences in the mean visibility distances did not exceed above 15%. Thus, test reliability is considered to be satisfactory.

Comparisons between U.S. low and high beams showed that on two-lane roads visibility is greatest if dimming occurs from high to low beams at about 1500 feet. The U.S. low beam headlamps used in these tests provided greater visibility of a target on the right side of the lane than the European H_4 headlamps that were used. A type of mid beam provided greater visibility on the right than the U.S. or European beams.

Road evaluations of glare from the headlamp beams showed that the European high beam produced relatively much more requests for dimming from oncoming drivers than the U.S. high beam. Drivers were also influenced by the number of headlamps on the oncoming vehicle, but not in the case of the following vehicle. Discomfort glare due to beams reflected in rearview mirrors was affected by mirror reflectivity and beam intensity, but not by the presence or absence of road lighting.

Mortimer, R.G. and Olson, P.L. Evaluation of Meeting Beams by Field Tests and Computer Simulation. Highway Safety Research Institute, The University of Michigan. Report No. UM-HSRI-HF-74-27, December 1974.

The objective of this study was to conduct field experiments to evaluate alternative meeting beams in terms of visibility distances and glare effects. The conventional U.S. and European low beams were used as a basis for comparison with the experimental mid beams.

Computer simulation evaluations were first made to indicate the most effective aim of the Type-III lamp used to augment the conventional low beam headlamps in providing mid beams. Two aiming specifications for this lamp were derived, in one of which the lamp was aimed with its maximum intensity 2^{0} R, 0.5^{0} D and in the other 2.5^{0} R, 1.0^{0} D. The former was intended to provide greater visibility and somewhat greater glare while the latter was intended to produce lower glare values and lower visibility.

Results of the field tests showed that visibility of Type-I targets positioned in the center of the two-lane road used, was about half that for targets at the right side of the lane. The visibility distances for the targets in the left of the lane were not different with the various beams, except at close to the meeting point where the beams using the European low beam provided slightly greater visibility. For targets on the right of the lane, the mid beam A and the ECE-U.S. mid beam produced the greatest visibility distances, up to 24% greater than the low beams by themselves. The results of this test and corresponding conditions in previous studies were in reasonably good agreement, indicating that the procedure was fairly reliable. Glare ratings were found not do differ between the beams for targets on the right side of the road but for targets on the left side of the road the glare ratings were better for the two beams using the European low beam than the mid beams A or B. Visibility distances for a pedestrian target were about the same as for the Type-I target used in these studies. The data suggest that a mid beam, composed of the ECE low beam and a Type-III lamp can be expected to provide about a 20% increase in seeing distance for targets along the right side of the road with negligible increases on glare for meetings on straight, flat, two-lane roads.

There was generally good agreement between computer simulation predicted visibility distances and those obtained in the field test.

It was concluded that improved meeting beams should incorporate the general characteristics of the mid beams used in these tests and that, based on the test findings and those of previous computer simulations, the mid beams should be dimmed when meeting another vehicle which is in the outside lane and when following another vehicle at distances of less than about 200 ft.

Nelson, J.H. Design and Use of Headlamp Meeting Beams. Proceedings of the Institute of Mechanical Engineers, Auto Division. Vol. 3, 1954-55, 100-107, 117-129.

This is a very general paper on the historical development of headlighting and some general criteria which should be considered in headlamp design. It also contains an accounting of the historical development of headlamp philosophy in this country as well as in Europe.

Ohlon, R., Zaccherini, F. Design Considerations for a New Passing Beam. Statens Provningsanstalt/rapport. C-Ra-233, Stockholm, 1972.

This paper begins with a comprehensive review of the seeing distance studies reported by Rumar et al. (1973) and speculates as to why the very large seeing distances reported in that study may have come about. The authors prepare an analysis of the light directed down the road at various heights above the roadway surface in an effort to determine the correlation between luminance intensity and seeing distance. It is found that the maximum correlation between these values occur at a height which corresponds approximately to the top of the one meter high targets used by Rumar et al. The authors therefore conclude that the superiority of the American beam in these tests are attributable to light emitted just below the horizontal. On a basis of these observations, the authors recommend a new passing beam design. A rough approximation of this may be visualized by taking a typical European style low beam and shifting it somewhat to the left.

Olson, P.L. and Mortimer, R.G. Investigation of Some Factors Affecting the Aim of Headlamps. Highway Safety Research Institute, University of Michigan. Report No. UM-HSRI-73-13, January 31, 1973.

A review of factors that are likely to contribute to misaim of headlamps is followed by a series of studies to evaluate the role of some of those factors.

Headlamp aiming methods are evaluated in terms of the variability to aim introduced by subtasks such as: the use of the sights used for finding the vehicle's long axis, finding the long axis of the vehicle, and aiming the lamps. Differences were found in the effectiveness of the sights, and finding the long axis was dependent on the availability of a prominent hood centerline on the vehicle. The photometric device provided lower variability in aiming a headlamp than a visual machine, with the latter less effective than the use of a large aiming screen. When the errors due to use of a sighting device and finding the vehicle's long axis are included, both the photometric and the visual machines introduce considerable errors, particularly in the horizontal. On the easiest to aim cars, with clearly defined centerlines, the photometric and visual machines, respectively, would allow about 95% and 50% of the aim of headlamps to fall in the SAE specifications.

The quality of headlamp aiming by service stations, repair shops and dealer service departments was found to be a contributor to poor aims, since only 38% of the outlets aimed all four lamps on a test car to within specifications. By comparison, a survey of the headlamp aim of new cars on dealers' lots, in as-received condition, showed that at worst 35% and at best 95% of the cars on any one lot were within specification.

The effect of vehicle service on aim was investigated by periodically checking the aim of a sample of vehicles. Most of the change in aim occurred in the first two months of the eight-month survey, and amounted to a standard deviation in aim of 0.3^{0} vertically and 0.2^{0} horizontally for passenger cars. The changes in headlamp aim that occurred in a sample of trucks over a period of six months was larger than found for the automobiles.

Vehicle loading effects were found to be substantial, and usually raised the beam.

It was concluded that improved training of service personnel in the use and maintenance of aimers is needed. Mechanical aimers offer greater reliability than other types. Ways need to be found to reduce the errors in locating the vehicle's long axis, before other methods can be recommended. Since factory aim is generally better than in the service trade, it may be suggested that new car aim should be checked but not disturbed unless a large error is found.

Other factors, such as alignment problems caused by radial tires, interference of bezels, and reduction in the friction of headlamp aim adjusting mechanisms, are discussed.

Powers, L.D. and Solomon, D. Headlight Glare and Median Width. Highway Research Record, No. 70, 1965, 1-27.

Three study methods were explored for determining the effect of location of an opposing glare vehicle on visibility at night. Both lateral separation and logitudinal distance between glare vehicle and observer were varied. In study one, both glare car and target were stationary. The observer drove toward the target and indicated when he could detect it. In study two, both target and observer were stationary while the glare car moved toward the observer. Locations of the glare car were found for which the target was just visible to the observer. Study three involved a self-illuminating target and, as in study 2, both target and observer were stationary while the glare car moved toward the observer. The observer continuously adjusted the brightness of the target and attempted to keep it barely detectable. Some limited measurements of discomfort due to glare were made, but this line of investigation was abandoned due to high variability in the results and a lack of an adequate definition of discomfort.

The results showed that the effects of glare decreased with increasing lateral separation of the glare car as expected. At any given lateral separation, the effects of glare were present, even when the glare car was at a considerable distance from the observer (3,000 ft. or more). The rate of change of the effect with distance was small for a large part of this distance. Recommendations are made for the conduct of target detection studies of this type. Remarks are made concerning the visual problems in night driving and possible areas for future investigation are suggested.

Roper, V.J. Four Headlamps for Better Seeing. Traffic Engineering, Vol. 27, January 1957, 171-175.

This is a description of the development of headlighting systems up to the four headlamp system first introduced in 1957. The article is written for popular consumption but contains a number of interesting insights into the various steps which led to the development of a four lamp system. It was pointed out, for example, that a four headlamp system was developed much earlier but met with objections from a point-of-view of aiming difficulties and styling problems. It is also pointed out that stylists were one of the driving forces behind the development of the four lamp system.

Roper, V.J. and Meese, G.E. More Light on the Headlighting Problem Highway Research Record, No. 70, 1965, 29-34.

Written in a rather breezy and informal way, this is a description of a number of tests carried out by General Electric comparing various factors influencing headlamp performance. There were a number of tests to examine different candlepower outputs of lamps on both straight and curved roads. There was another study carried out to evaluate the effect of misaim. Another study on the effect of mounting height. There was a study which compared a low beam European quartz halogen lamp with an 8,000 candlepower U.S. low beam lamp. The results of this are quite similar to those reported from HSRI in that under low glare conditions the European lamp did not do as well as the American lamp but under high glare conditions the results were quite comparable. Finally, there is a study comparing the effect of alcohol on seeing distance using American style lamps.

Roper, V.J. and Morgenstern, L.A. Quartz-Iodine Headlamps Slated for European Debut. SAE Journal, Vol. 72, No. 6, June 1964, 30-35.

This article gives a technical run-down on the principle behind the quartz halogen headlamp. It contains a brief history of the development of the concept and contains a number of derogatory comments regarding the European principle of automotive headlighting.

Rumar, K. Visible Distances in Night Driving with Misaligned Meeting Dipped Headlights. Department of Psychology, University of Uppsala, Sweden, Report No. 28, August 1965.

In order to examine how the visible distances of drivers during a car meeting changes with vertical adjustment of the headlight of the meeting car, a series of tests have been carried out. The meeting car with easily adjustable headlights in the vertical direction was stationary. The subject drove the other with correctly adjusted headlights. The adjustment of the headlights was varied at random in steps of 1 degree, from 2 degrees too low to five degrees too high. The result was, that compared to correctly adjusted meeting lights, the visibility distance was not increased by a downward misalignment of meeting headlights, while on the other hand, an upward misalignment of $1\text{-}2^{0}$ of meeting headlights decreased the normal visibility distance 25%.

It should be noted that this test was run with European style asymmetric beams. Because of the sharp cutoff characteristics of such headlamps it would not be expected that downward misalignment would have very much effect. Slight upward misalignment, at least by 1 or 2 degrees would be expected to have a major affect, which in fact is what is shown by the tabulated data. Misalignment much greater than 2 degrees upward would begin to throw the hot spot above the eyes of the oncoming driver, reducing the glare problem.

Rumar, K. Visual Performance in Night Driving. Interdisciplinary Studies from the Scandinavian Summer University. Vol. XIII, 1966, 9-18.

This is a general summary of the earlier work carried on at Uppsala by Rumar and his coworkers. It includes a review of the early seeing distance studies, the headlight adjustment study, the silhouette effects study and a study concerning readaptation time after glare.

Rumar, K. Halogen and Conventional Continental European Headlights: A Comparison of Visibility Distances. Department of Psychology, University of Uppsala. Report 94, 1970.

Using visibility distance as a criterion, halogen and conventional high and low beams have been experimentally compared in a series of field tests. The main results were as follows:

On high beam, without opposing light, the halogen headlights offer about 25% longer visibility distances than the conventional headlights. With both opposing cars using low beam there is a slight advantage (less than 5 meters) to have halogen headlights. The optimal dipping distance is a function of high beam system (intensity) rather than low beam system.

Small differences in aiming, atmosphere, etc., cause larger differences in visibility distance than does the headlight system under consideration.

Rumar, K., Helmers, G., and Thorell, M. Obstacle Visibility with European Halogen H4 and American Sealed Beam Headlamps. University of Uppsala, Sweden, Report 133, 1973.

This report describes a series of field experiments which measured visibility distances comparing European and American headlamp beams. The tests were carried out for various relevant traffic situations. The tests were carried out in a semi-dynamic fashion with a static glare car parked on one side of a two lane road and the subjects (carried four at one time) in an experimental vehicle, which was driven toward the glare car at a speed of 50 kilometers per hour.

Results indicate that the European high beam provided approximately a 15% increase in visibility distance to a gray object measuring 0.4 meters broad and 1.0 meters high on straight roads. On sharp curves the difference between the European and American high beams is negligible.

In an experimental setting where a low beam was opposing a low beam, it was found that the difference between the two lighting units produced the following visibility results:

1. Under normal, i.e., straight road conditions, it was always a considerable advantage (30-40%) to have an American low beam and a slight disadvantage to meet an American low beam (10%) compared with an European style low beam.

2. The American low beam advantage is larger the higher the reflectivity level of the obstacles or test targets.

3. Under conditions of missing headlights, it was always a considerable advantage to use the American style low beam.

4. The two systems gave roughly even visibility on sharp curves with an advantage with the American unit on sharp curves to the left.

5. Subjectively the European beam was estimated superior to the American beam, even in situations where they gave shorter visibility distances. A special glare evaluation was carried out by pedestrians and opposing drivers and it clearly showed the higher perceived glare for the American style beams. However, there was no indication of real discomfort or irritation on the part of the observers.

The investigation demonstrates clearly that low beam vehicle lighting visibility is far from acceptable in relation to normal speeds in night driving. Strong efforts should be made to increase visibility distance further. The authors feel that a good interim improvement could be realized by switching to an American beam pattern.

Schreuder, D.A. Vehicle Lighting System - Four Steps in Glare Reduction. Proceedings of the Society of Photo-Optical Instrumentation Engineers, November 1972.

This is a very general article which tries to set forth the problem of information acquisition in night driving and then discusses four ways in which glare reduction can be brought about. It begins by talking about the development of the current European low beam lamp and then goes on to discuss multiple beam systems, three and four beams of various configurations which ease the transition between high and low beams and make possible greater choices for the driver under different driving conditions. It then goes on to a discussion of beam stabilization systems designed to compensate for different degrees of pitch on the vehicle. It concludes with a discussion of polarized lighting.

Schiflett, S.G., Candena, D.G., and Hemion, R.H. Headlight Glare Effects on Driver Fatigue. Southwest Research Institute, Project No. 11-1908. Report No. AR-699, September 1969.

Two separate studies were conducted with real and simulated night operation to examine the phenomenon of fatigue in drivers by a variety of physiological and psychophysiological sensors and indicators including, EEG, EMG, Reaction and Task Performance Measures and changes in 17-OHCS level in body fluids. The objective of these studies was to differentiate the onset and development of fatigue in drivers with respect to specific modes of opposing vehicle headlights. The experiments were essentially unsuccessful in finding a sensory technique of adequate sensitivity to provide such discrimination.

Schwab, R.N. Night Visibility for Opposing Drivers with High and Low Headlight Beams. Highway Research Board, No. 70, 1965, 87-88.

This is a very brief article, an abridgement of another article, which is primarily concerned with differences in performance of headlights as measured in conventional test situations as a function of the target used. In this study two different types of targets were employed, a red retroreflector on the rear of an unlighted black car and a section of standard pavement stripe. Results indicated that quite different results were obtained as a function of beam with the two different targets. The author states that these results show the danger of using a single simplified target in research on driver visibility.

Schwab, R.N. and Hemion, R.H. Improvement of Visibility for Night Driving. Highway Research Record, No. 377, 1971.

This paper is a general overview of the research and headlighting carried out at the Southwest Research Institute. There is a brief discussion of the beam use study and the visibility studies, but the bulk of the paper is devoted to the polarized headlighting work and there are a number of sections dealing with various aspects of that problem. It closes with a brief discussion of fixed lighting systems.

Tsongos, N.G. and Schwab, R.N. Driver Judgments as Influenced by Vehicular Lighting at Intersections. Highway Research Record, No. 336, 1970, 21-32.

The driver's judgments and decisions at a right angle non-signalized intersection in relation to the degree of glare exposure were examined by using both conventional and polarized headlighting. The study was conducted on a runway of an airport in a dark rural environment. Two types of procedures were employed during the test. In the first, the subject driver stationed in a vehicle was asked to judge the "last safe moment" to start across the intersection ahead of the approaching test vehicle from the right. In the second procedure, the test driver performed the crossing maneuver. Two age groups of ten male drivers each were recruited to participate in the experiment. Statistical analyses show significant differences in the drivers reaction among different lighting modes. Under the more glaring conditions the subject drivers required longer gap acceptance time and there was greater variance in the data. Both age groups had the same pattern of gap acceptance values for each lighting mode. In the performance runs the younger age group had shorter gap acceptance values and less variability among drivers. Although low beam lamps were least bothersome according to the discomfort glare evaluation done by the subject drivers, both polarized high beam systems studied were superior to conventional high beam systems.

Webster, L.A. and Yeatman, F.R. An Investigation of Headlight Glare as Related to Lateral Separation of Vehicles. University of Illinois, College of Engineering, Engineering Experiment Station, Bulletin 496, 1968.

This is a very comprehensive paper describing research largely related to means for glare reduction. The means explored are lateral separation and polarization. There is no description of any work comparing European and American style beams. However, there is a very comprehensive literature review in the first part of the paper.

Woodward, F. and Wolfe, K.R. Headlamps for the Future. Automobile Engineer, Vol. 6, No. 7, July 1971, 42-45.

This is a good article which describes the basic features and advantages and principles behind the tungsten-halogen cycle. On the last page of the article is a brief consideration of the relative merits of the Anglo-American and European type beam patterns.

Yerrell, J.S. Headlamp Intensities in Europe and Britain. Road Research Laboratory, RRL Report LR 383, 1971.

A survey of headlamp intensities was made in Britain and four European countries. Meeting beam intensities causing glare and giving near side illumination were recorded. Average intensities in the glare direction in Britain were nearly double those on the continent, with intensities in France being higher than the continental average and more diverse. Comparison with an earlier survey suggests little change in the glare situation in the United Kingdom in the past eight years. British values were closer than the continental to the relevant beam specification. Illuminating intensities around 4,000 candela were recorded at all four British sites. The single French site almost doubled the remaining European figures. There was no correlation between illumination and speed. A driver's ability to see during a meeting situation depends on both glare and illumination. Tentative conclusions based in the illumination values suggest that the British drivers would have seen a standard target 60 meters away at the roadside in 44% of meeting situations on a two-lane road compared with 56% for the French drivers, and 21% for the Belgian. Low illumination was responsible for this last low figure, not excessive glare.

Zaccherini, F. and Thulin, A. A Survey of Motor Vehicle Headlights. Stockholm, P66-332, Final Report, Lab C 12. 1969.

This is an English translation of an article which was published originally in 1967. It thus pre-dates the quartz halogen and some of the comments, particularly those relating to blackening of the bulb are inappropriate. The report is very difficult to follow, and apparently many pertinent details are missing. However, it relates to a laboratory investigation of a number of factors concerning European and American headlamps. The report implies that there was substantial deterioration in the European lamps associated with moisture and dust being brought into the lamp housing during the operational cycles. The authors found significant reductions in overall performance and loss of proper photometric distributions. The authors conclude that American lamps are much better in this respect and urge a detailed test program to determine whether in fact American lamps ought to be used in Sweden.

Zechnall, R. Influence of Light Distribution of Headlamps on Seeing Distances. Lighting Problems in Highway Traffic. Proceedings of a Symposium held at the Wenner-Gren Center, Stockholm Sweden, October 1962, 53-72.

This is a good description of differences between American and European beam patterns from a number of points of view. Of particular interest is the description of cutoff requirements beginning on page 58. This culminates in a discussion on pages 60 and 61 which argues for a relatively sharp cutoff and therefore argues that the American low beam is inferior.