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Effect of Tinted Windshields and Vehicle Headlighting on Night Visibility

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Effect of Tinted Windshields and Vehicle Headlighting on Night Visibility

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Osterhoudt, E.W., Traffic Engineer, Connecticut State Highway Department, State Office Building, Hartford 15, Connecticut

Post, C. F., Manager, Signal Service Division, American Gas Accumulator Company, 1027 Newark Avenue, Elizabeth 3, New Jersey

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Rhodes, John B., Vice-President, American Gas Accumulator Company, 1027 Newark Avenue, Elizabeth 3, New Jersey

Roper, Val J., Lamp Department, General Electric Company, Nela Park, Cleveland 12, Ohio

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Van Heuckeroth, A. W., Chief, Materials Branch, Engineering Research Development Laboratory, Corps of Engineers, Fort Belvoir, Virginia

Vey, Arnold H., Director, Bureau of Traffic Safety, Department of Law & Safety, State House, Trenton 7, New Jersey

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EFFECT of TINTED WINDSHIELDS on NIGHTTIME-VISIBILITY DISTANCES

Warren Heath, Automotive Engineer
California Highway Patrol
and
D. M. Finch, Associate Engineer
Institute of Transportation and Traffic Engineering
University of California

IN the past several years there have been developments in the glazing of motor vehicles that may affect the visibility distances of roadway obstacles. These developments have been made primarily to provide a glass which is effective in reducing radiant-heat transmission into a vehicle. Chemical compositions, usually utilizing iron, are employed so the glass will absorb a large quantity of infra-red radiation. The changes made to reduce the heat transmission of the glass also reduce the transmission of light in the visible region if the glass is to be at all effective, since most of the heat of the sun is radiated in the visible spectrum. In general, the absorption of infra-red radiation causes the transmittance for safety windshields to be reduced from values in the order of 87½ to 89½ percent for standard safety plate to values in the order of 71 to 73 percent for heat-absorbing and tinted safety plate when using a tungsten filament light source at a color temperature of 2,848 K.

In addition to increasing the heat absorption of the glass itself, other changes have been made in the plastic sheets used to laminate the safety glass. Tinted colors are used in order to increase the comfort of daytime driving. Some of the tinted plastic laminations have a uniform density while others have a graduated density with greatly reduced transmission in a narrow band at the top serving to reduce sky glare.

State officials faced with the problem of approval of safety glass have had to appraise the effect of various glazing materials on the safe operation of motor vehicles. The usual basis for such appraisal is tests made in accordance with American Standards Association specifications (1). The tests normally made on the glazing materials cover the physical factors of strength, stability, quality, and light transmittance. The tinted and heat-absorbing glass produced by the principal manufacturers and now on the market have been found to conform to the ASA Safety Code.

The subject in question is the effect on visibility distances of safety glass having a light transmittance that has been purposely reduced to approximately the ASA minimum of 70 percent. Is the present minimum an adequate requirement, or is it so low as to increase the hazards of night driving when windshields barely meeting the specification are used in place of presently available safety glass having greater light transmission properties?

OBJECT OF INVESTIGATION

It has been the object of this investigation to attempt to establish actual driver test conditions which would indicate whether or not any differencesin nighttime visibility distances result from a change in the color and visible-light transmittance of the windshield.

Since the number of variables in any test of visibility distances is large and since the extent of this test program was necessarily limited, it was felt that the most significant type of test would be one in which drivers were performing under actual roadway conditions with as many of the roadway conditions controlled as possible. This method of attack was selected in lieu of a laboratory test procedure in order to obtain a more readily acceptable evaluation of the effect of tinted windshield glass on visibility distances. Tests were not made against opposing headlamps since data of this type were concurrently being obtained by the Automobile Manufacturers Association (2).

EXPERIMENTAL PROCEDURE

Visibility distances were measured by a recorder mounted inside the vehicle. A drum driven by the speedometer cable through a gear reduction box of approximately 600 to 1 transported paper past a marking pen. The pen produced a continuous line on the unrolling paper strip. When a control button was pressed, the pen moved laterally producing an offset line until the button was released.

The observer-driver momentarily pressed the hand-held button when the roadway object was first seen and then again at the time the object was passed. The distance between the lateral marks on the paper could later be measured with a calibrated scale to obtain the visibility distance for each observation. The gear reduction was such that 1 in. on the paper equalled a distance of 250 ft. traveled by the vehicle. Readings could easily be made to the nearest 5 ft.

The vehicle used for the tests was the technical research unit of the California Highway Patrol, which had a two-piece, curved windshield. The left half of the windshield mounting was modified so the clear glass and the green-tinted glass could easily be interchanged. The tinted glass used in the tests was E-Z-Eye Hi-Test LOF Safety Plate having a visibile light transmittance of 71 percent, measured perpendicular to the surface. An upper 4-in. shaded section gradually increased in density toward the top. Observations were made only through the lower part of the glass having uniform transmittance.

The clear glass employed as a standard was Hi-Test LOF Safety Plate having transmittance of 89 percent. The light transmittance for the particular samples used in the test was measured using a color corrected photocell and a light source at a color temperature of 2,900 K. The values for the tinted and clear glass slanted at 45 deg., as in the vehicle, were found to be 69 and 86 percent respectively. Under these conditions the transmittance of the tinted glass was 20 percent less than that of the clear glass.

The site for the tests was a 2-mi. stretch on the newly completed San Lorenzo to San Leandro section of the East Shore Freeway near Oakland, California. This four-lane, divided highway was paved with longitudinally broomed concrete and had not been opened to traffic. The highway was unlighted and there was no light from opposing headlamps to interfere with vision. All of the test section except a portion at one end was located in an unpopulated area. At a few points luminaires from distant streets came into the field of view causing some disturbance in seeing about three of the objects.

Sixteen objects were used for most of the runs. The first tests were made with objects of different sizes and shapes, and the last ones with all objects the same. No attempt was made to place the objects in exactly the same location for each observer. The car was driven at a speed of 50 mph. with the headlamps on low beam and with the adjustable dash lamps at maximum brightness.

At the beginning of the study, in each of the first three series, all of the observations with one type of glass were run before the windshield was changed. During the last four tests the glass was changed every six runs to reduce possible effects of a gradual change in ambient lighting, driver fatigue, and other conditions with the passage of time.

Two of the observers wore vision-correcting glasses, and one had normal vision without glasses. The observations were made without the driver knowing what the numerical results of his observations were. The observers knew they were being tested, were concentrating on the seeing tasks, and had a knowledge of how the results were to be used. The observations are, however, considered to be unbiased by such knowledge. The long-visibility distances obtained on low beam will not normally apply under average driving conditions where the driver is less alert. The relative distances between tinted glass and clear glass should be reasonably the same.

EXPERIMENTAL RESULTS

The results obtained during the complete series of tests are contained in Tables 1 to 8. The number of runs, the arithmetic mean, and the standard deviation of the observations are given for each object viewed through the clear and the green-tinted windshields.

The difference between the averages is given both in feet and as a percentage of the average for the clear glass. Underlined values indicate the green-glass readings were greater than the clear-glass readings.

The difference divided by its standard deviation (D/σ_d) furnishes an indication of the probability of a significant difference between the two types of glass. Assumptions that there is an actual difference would be correct 84.2 percent of the time for a value of $D/\sigma_d = 1$; 97.7 percent for a value of 2; and 99.9 percent for a value of 3.

The probable error of the difference by standard statistical definition is 0.675 times the standard deviation of the difference expressed as a percentage of the clear glass average. This means that there is a

50-50 chance that the average difference of all possible readings for the same object under the particular conditions existing at the time of the test will fall within the average difference of the observed readings plus or minus the probable error.

The equations used for the standard deviation of the means were

$$\sigma_{\bar{X}} = \frac{\sigma_s}{\sqrt{N-1}} \text{ for 30 or more readings,}$$

$$\sigma_{\bar{X}} = \frac{\sigma_s}{\sqrt{N-2}} \text{ for 11 to 29 readings, and}$$

$$\sigma_{\bar{X}} = \frac{\sigma_s}{\sqrt{N-3}} \text{ for 5 to 10 readings,}$$

The computed standard deviations of the differences are not too reliable, in most cases, due to the small number of observations.

TABLE 1

OBSERVER: W. M. Heath
DATE: 6 December 1951 Half Moon

Object		N_c	$\bar{X}_c$	σ_c	N_g	$\bar{X}_g$	σ_g	D	σ_d	Diff.	Probable Error
			ft.	ft.		ft.	ft.	ft.		%	%
1.	Westbound	8	304	28	7	287	29	17	19	5.6	±4.2
2.	Westbound	9	305	11	6	290	15	15	10	4.9	±2.2
3.	Westbound	9	305	11	6	283	23	22	14	7.2	±3.1
4.	Westbound	9	578	43	5	511	43	67	35	11.6	±4.1
5.	Eastbound	9	534	74	9	474	40	60	34	11.2	±4.4
6.	Eastbound	9	540	24	8	505	21	35	13	6.5	±1.7
7.	Eastbound	8	440	17	10	409	35	31	15	7.1	±2.4
8.	Eastbound	6	265	26	10	282	20	17	17	6.4	±4.3

Underlined values indicate green average is greater than clear average.

Runs 1 - 12 inclusive - green glass
Runs 13 - 22 inclusive - clear glass

Objects: (first dimension is vertical)
1. Dark-green board (2½ ft. by 1 ft.)
2. Weathered planks in inverted V (3 ft. by 3 in.)
3. Weathered plank (3 ft. by 1 ft.)
4. Light pine box (3 ft. by 1 ft.)
5. Aluminum bucket (8 in. by 8 in.)
6. Light pine box (1 ft. by 3 ft.)
7. Olive-drab box (2½ ft. by 1½ ft.)
8. Dark-green board (1 ft. by 2½ ft.)

TABLE 2

OBSERVER: D. M. Finch
DATE: 20 December 1951 No Moon

Object	Nc	$\bar{X}_c$	σ_c	Ng	$\bar{X}_g$	σ_g	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.		%	%
1. Westbound	11	255	24	9	201	34	54	16	21.2	±4.3
2.	11	386	44	9	325	22	61	18	15.7	±3.1
3.	11	381	24	10	337	37	44	16	11.5	±2.8
4.	11	313	19	9	263	11	50	8	15.8	±1.7
5.	11	344	25	10	328	32	16	18	4.5	±3.5
6.	11	217	37	10	201	18	16	14	7.5	±4.4
7.	11	403	20	10	362	31	41	14	10.1	±2.3
8.	11	447	38	10	400	25	47	16	10.6	±2.4
9. Eastbound	11	393	24	8	339	22	54	13	13.7	±2.2
10.	11	316	18	10	251	20	65	10	20.4	±2.1
11.	11	296	22	10	243	20	53	11	18.0	±2.5
12.	11	345	20	9	291	22	54	11	15.7	±2.3
13.	11	310	22	10	264	28	46	13	14.8	±2.8
14.	11	323	28	9	252	23	71	14	21.8	±2.8
15.	11	265	13	10	208	19	57	9	21.4	±2.2
16.	11	389	21	9	349	22	40	12	10.3	±2.0

Runs 1 - 12 inclusive - green glass
Runs 12 - 23 inclusive - clear glass

Objects on drainage curb
Vehicle in right lane

Objects: (first dimension is vertical)
1. Dark-green board (20 in. by 16 in.)
2. Galvanized panel (16 in. by 20 in.)
3. Red, white, and black sign (1 ft. by 1½ ft.)
4. Weathered planks in inverted V (3 ft. by 3 in.)
5. Aluminum bucket (8 in. by 8 in.)
6. Dark-green board (1 ft. by 2½ ft.)
7. Olive-drab box (3 ft. by 1½ ft.)
8. Light pine box (2½ ft. by 1 ft.)
9. Stake on shoulder (3 ft. by 2 in.)
10. Weathered plank (3 ft. by 1 ft.)
11. Weathered planks in inverted V (3 ft. by 3 in.)
12. White sign (1 ft. by 1½ ft.)
13. Light colored rock (approx. 8 in. dia.)
14. Dirt pile (1½ ft. by 3 ft.)
15. Green tool box (15 in. by 8 in.)
16. Aluminum painted drain grate

Table 3 shows the results of tests made using green-tinted glasses. The observer in the series of tests here reported normally wears vision-correcting glasses, and on this particular date he was wearing a green-tinted pair. This fact went unnoticed at the time both by the observer and the passenger, so the results were not prejudiced by such knowledge.

TABLE 3

OBSERVER: B. Andrews (green-tinted glasses)
DATE: 3 January 1952 Quarter Moon during last part of test

Object	Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.		%	%
Westbound										
1.	19	228	29	19	239	43	11	13	4.8	±3.8
2.	20	393	44	18	414	35	21	14	5.3	±2.4
3.	19	229	24	20	229	31	0	9	0	±2.8
4.	20	318	39	19	343	53	25	16	7.8	±3.4
5.	20	344	24	19	351	29	7	9	2.0	±1.8
6.	19	412	46	20	430	44	18	15	4.4	±2.4
7.	20	445	36	20	482	40	37	13	8.3	±1.9
8.	20	206	27	20	221	20	15	8	7.3	±2.6
Eastbound										
9.	20	402	19	20	405	39	3	10	0.7	±1.7
10.	19	373	36	20	388	34	15	12	4.0	±2.2
11.	20	313	21	20	326	34	13	9	4.1	±2.0
12.	20	394	38	20	409	54	15	16	3.8	±2.7
13.	19	400	50	19	442	48	42	17	10.5	±2.8
14.	20	287	23	19	291	23	4	8	1.4	±1.8
15.	20	396	40	20	429	73	33	20	8.3	±3.4

Underlined values indicate green average greater than clear average.

Objects on drainage curb
Vehicle in right lane

Runs 1 - 20 inclusive - clear glass
Runs 21 - 40 inclusive - green glass

Objects: (first dimension is vertical)
1. Dark-green board (2½ ft. by 1 ft.)
2. Galvanized metal panel (16 in. by 20 in.)
3. Weathered plywood (6 in. by 24 in.)
4. Weathered plank (3 ft. by 1 ft.)
5. Aluminum pan (1 ft. by 2 ft.)
6. Brown composition sheathing (3 ft. by 5 ft.)
7. Light pine box (3 ft. by 1 ft.)
8. Dark green board (1 ft. by 2½ ft.)
9. Olive-drab box (3 ft. by 1½ ft.)
10. Red, white, and black sign (16 in. by 20 in.)
11. Weathered planks in inverted V (3 ft. by 3 in.)
12. Light wood frame (18 in. by 24 in.)
13. Galvanized metal panel (20 in. by 16 in.)
14. Green toolbox (8 in. by 16 in.)
15. Light wood frame (18 in. by 24 in.)

It was felt the results in Table 3 may also have been influenced by light from the moon which rose during the last half of the runs, especially since all of the clear runs were made first, followed by all of the green runs. In order to determine if there was an increase in visibility distance with learning or with an increasing amount of light, the curves in Figures 1 and 2 were plotted showing the visibility distance versus the order of the runs. The objects selected were the two having the least and the most difference between the green and clear averages in each direction of travel.

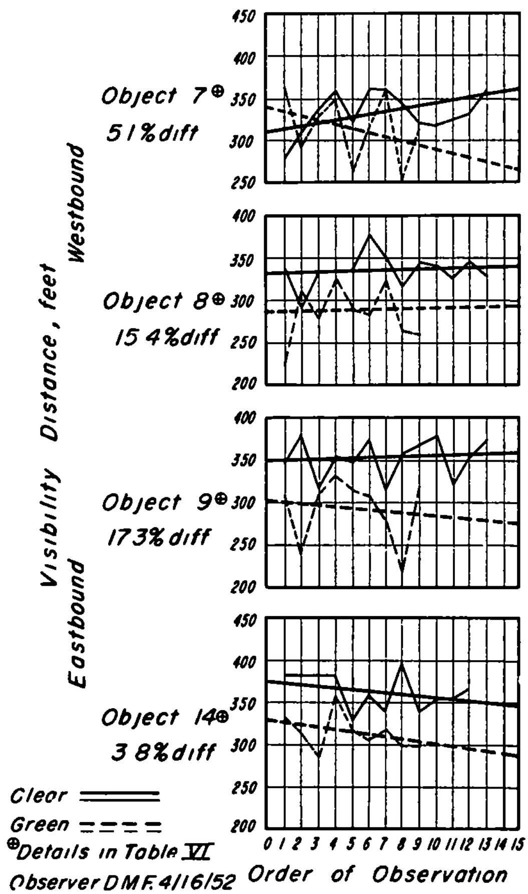

Figure 1. Nighttime-Visibility Distances.

A trend line drawn through the points would indicate changes in seeing distance with the passage of time. Straight-line trends were computed using the method of least squares and employing a moving average of three readings to smooth out the extreme values. For purposes of comparison, Figure 1 is shown with data from Table 6 for a night in which there was no moon and during which the glass was changed every six runs. It can be seen that the trend lines are substantially different for each of the objects shown.

An examination of Figure 2 in which the green-glass values were greater than the clear-glass values shows no trend which was consistent for all the objects selected. There is no general increase in seeing distance with the passage of time as would be the case if the slightly increased illumination due to the moon, or if the driver's learning were to primarily account for the seeing distance being greater with the green windshield than with the clear when tinted glasses were being worn. However, the green readings for the west-bound objects show an upward trend, whereas the reverse is true for the east-bound objects. In the west-bound runs the moon was slightly to the left and behind the observer, and for the east-bound runs it was slightly to the right and ahead of the observer, although at no time was it within the normal field of view while making the runs.

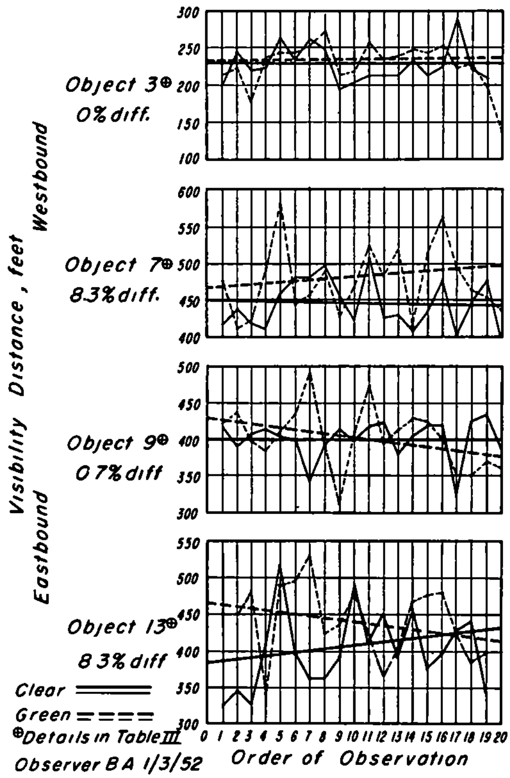

Figure 2. Nighttime-Visibility Distance.

Although all objects were the same for the data shown in Tables 4 to 7, there are considerable differences in the visibility distances of the 16 objects for each observer. A major part of the differences can be traced to the slightly uneven profile of the highway. The pavement was not a perfect plane in a longitudinal direction but had a shallow wave appearance in the daytime. The various objects were therefore lighted by different parts of the headlamp beam, depending upon the locations of the vehicle and object.

An experimental error was introduced into the results by the reaction of the driver when pressing the control button as he was passing the object. The difference between the longest and the shortest recorded distance measured between each pair of objects varied from approximately 20 to 50 ft. Although much of the error may cancel out, it would be well in any future tests to make each run from a fixed starting point. The exact location of each object could thus be fixed on the recording tape.

TABLE 4

OBSERVER: B. Andrews
DATE: 5 February 1952 No Moon

Object		Nc	$\bar{X}_c$	σ_c	Ng	$\bar{X}_g$	σ_g	D	σ_d	Diff.	Probable Error
			ft.	ft.		ft.	ft.	ft.		%	%
1.	Westbound	6	251	-	3	240	-	11	-	4.3	± -
2.		6	243	-	4	216	-	27	-	11.1	± -
3.		6	287	33	5	243	26	44	27	15.3	±6.3
4.		6	321	-	4	280	-	41	-	12.8	± -
5.		6	309	33	6	271	7	38	19	12.3	±4.2
6.		6	277	14	6	259	16	18	12	6.5	±3.0
7.		4	316	-	6	284	-	32	-	10.1	± -
8.		5	270	23	6	283	41	13	29	4.8	±7.2
9.	Eastbound	6	281	38	7	289	28	8	26	2.8	±6.3
10.		6	240	19	7	245	43	5	24	2.1	±6.8
11.		6	333	35	7	317	35	16	28	4.8	±5.7
12.		5	270	-	2	223	-	47	-	17.5	± -
13.		6	337	70	6	290	24	47	43	13.9	±8.6
14.		6	320	29	7	271	29	49	22	19.6	±4.7
15.		6	290	25	7	247	32	43	22	14.8	±5.1
16.		6	278	38	5	259	21	19	26	4.1	±6.7

Underlined values indicate green average greater than clear average.

Runs 1 - 3, and 11 - 13 inclusive - green glass
Runs 4 - 9 inclusive - clear glass

Objects in center of right lane
Vehicle in left lane

Objects: 12 in. by 11 in. unfinished new boards

Tests cut short because of ground fog forming in patches on last run.

The final series of tests given in Table 8 were made to eliminate some of the variables present in previous tests. Each run was started from a fixed point as suggested above, the speed of the vehicle was reduced from 50 mph. to 40 mph., and the objects used were covered with gray cardboard having a reflectance of 26 percent. The effect of better control of test conditions and an increased number of runs is revealed by the substantial reduction in the variation of percentage differences obtained for identical objects.

TABLE 5

OBSERVER: B. Andrews
DATE: 3 April 1952 Quarter Moon

Object		Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
			ft.	ft.		ft.	ft.	ft.		%	%
1.	Westbound	18	299	36	18	295	23	3	11	1.1	±2.4
2.	Westbound	18	298	36	18	286	38	12	13	4.0	±3.0
3.	Westbound	17	325	32	18	319	34	6	12	1.7	±2.5
4.	Westbound	18	331	33	18	316	23	15	10	4.4	±2.1
5.	Westbound	18	376	23	18	362	44	15	13	3.9	±2.3
6.	Westbound	18	358	27	18	353	28	6	10	1.6	±1.8
7.	Westbound	18	338	24	18	338	37	0	11	0.1	±2.2
8.	Westbound	17	312	40	18	309	72	2	21	0.7	±4.5
9.	Eastbound	17	384	38	17	365	26	19	12	4.8	±2.1
10.	Eastbound	18	354	36	17	339	23	15	11	4.3	±2.0
11.	Eastbound	18	375	46	18	380	44	<u>5</u>	16	<u>1.3</u>	±2.8
12.	Eastbound	18	338	39	16	341	31	<u>3</u>	13	<u>0.9</u>	±2.5
13.	Eastbound	18	417	58	18	371	35	46	17	11.0	±2.8
14.	Eastbound	18	365	43	18	329	29	36	13	9.9	±2.4
15.	Eastbound	17	385	39	18	357	50	28	16	7.3	±2.8
16.	Eastbound	17	343	39	17	317	45	26	16	7.6	±3.1

Underlined values indicate green average is greater than clear average.

Runs 1 - 3, 10 - 15, 22 - 27, 34 - 36 inclusive - green glass
Runs 4 - 9, 16 - 21, 28 - 33, inclusive - clear glass

Objects in center of right lane
Vehicle in left lane

Objects: 12 in. by 11 in. unfinished new boards.

TABLE 6

OBSERVER: D. M. Finch
DATE: 16 April 1952 No Moon

Object	Nc	$\bar{X}c$	σ_c	Ng	$\bar{X}g$	σ_g	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.		%	%
Westbound										
1.	12	328	17	9	296	21	32	10	9.9	±2.0
2.	13	317	29	9	295	39	22	18	7.0	±3.9
3.	12	337	17	9	301	19	36	9	10.8	±1.9
4.	12	335	19	9	297	23	38	11	11.5	±2.2
5.	12	326	32	9	303	17	23	12	7.0	±2.5
6.	12	347	32	9	312	24	35	14	10.0	±2.7
7.	12	331	27	9	314	39	17	18	5.1	±3.7
8.	13	336	18	9	284	32	52	14	15.4	±2.9
Eastbound										
9.	13	354	22	9	293	38	61	17	17.3	±3.3
10.	13	356	29	9	319	14	37	11	10.4	±2.1
11.	13	323	20	9	302	25	21	12	6.4	±2.4
12.	13	346	24	9	298	22	48	11	13.9	±2.2
13.	11	403	33	9	353	19	50	13	12.3	±2.2
14.	11	329	22	9	317	20	12	11	3.8	±2.2
15.	12	338	21	9	288	14	50	9	14.7	±1.7
16.	11	343	28	9	284	27	59	14	17.1	±2.8

Runs 1 - 3, 10 - 15 inclusive - green glass
Runs 4 - 9, 16 - 22 inclusive - clear glass

Objects in center of right lane
Vehicle in left lane

Objects: 12 in. by 11 in. unfinished new boards

TABLE 7

OBSERVER: W. M. Heath
DATE: 1 May 1952 Clear Sky, Quarter Moon

Object	Nc	$\bar{X}_c$	σ_c	Ng	$\bar{X}_g$	σ_g	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.		%	%
Westbound										
1.	6	409	22	7	387	26	22	18	5.4	±3.0
2.	6	408	38	7	393	29	15	26	3.7	±4.3
3.	6	420	56	7	385	37	34	37	8.2	±5.9
4.	6	432	25	7	443	43	<u>10</u>	26	<u>2.4</u>	±4.1
5.	6	431	21	7	425	42	6	23	1.3	±3.6
6.	6	419	32	7	413	30	6	24	1.3	±3.8
7.	6	417	11	7	396	26	21	14	5.1	±2.3
8.	6	418	22	7	418	37	<u>0</u>	22	<u>0.1</u>	±3.6
Eastbound										
9.	10	564	55	11	526	44	38	25	6.7	±3.0
10.	10	407	30	11	392	34	15	16	3.7	±2.7
11.	10	474	48	11	457	52	17	25	3.6	±3.6
12.	10	405	30	11	396	33	9	16	2.1	±2.6
13.	10	556	61	11	512	58	44	30	7.9	±3.7
14.	10	442	20	11	421	44	21	17	4.7	±2.5
15.	10	448	28	11	414	35	24	16	5.4	±2.4
16.	10	441	46	11	412	29	29	20	6.6	±3.0

Underlined values indicate green average greater than clear average.

Runs 1 - 3, 10 - 15 inclusive - clear glass
Runs 4 - 9, 16 - 22 inclusive - green glass

Objects in center of right lane
Vehicle in left lane

Objects: 12 in. by 11 in. unfinished new boards

TABLE 8

OBSERVER: W. M. Heath
DATE: 24 October 1952

Object	Nc	$\bar{X}_c$	σ_c	Ng	$\bar{X}_g$	σ_g	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.		%	%
Northbound										
1.	28	415	34	27	396	42	19	11	4.6	±1.8
2.	27	413	35	27	401	46	12	12	2.9	±1.9
3.	27	409	40	28	395	82	14	10	3.5	±1.5
4.	24	414	52	28	385	61	29	17	7.0	±2.7
5.	24	419	44	28	410	58	9	15	2.1	±2.4
Southbound										
6.	28	395	62	30	375	32	20	14	5.1	±2.4
7.	28	417	21	31	391	38	26	7	6.3	±1.2
8.	26	428	37	30	403	33	25	10	5.9	±1.5
9.	25	443	46	31	418	38	25	12	5.7	±1.8
10.	25	480	45	31	448	49	32	13	6.6	±1.8

Runs 1-10, 21-30, 41-50, and 61-64 inclusive -- clear glass
Runs 11-20, 31-40, and 51-60 inclusive -- green glass

Objects located to right of vehicle

Objects: 8 in. by 12 in. gray cardboard having 26 percent reflectance.

DISCUSSION

The tests were undertaken after a preliminary study made by us in 1951 showed a need for more extensive data (3). The previous experiments consisted of two runs each by five observers and employed three objects. The data gave changes in seeing distance of from + 6 percent to -71 percent, depending on the object and the observer. The results were not considered conclusive, due to the wide variations in readings and the small number of runs.

The present study did not include runs against opposing headlamps as such tests using heat absorbing glass were being made in Florida by the Automobile Manufacturer's Association (2). Results of the Florida study show values for one of the objects comparable to those we obtained. Table 9 gives data from the AMA report on the last object approximately 1,700 ft. past the meeting point.

The values of the probable error of the difference were computed by us. The last object was picked as a comparison since conditions of no glare similar to the tests reported herein prevailed. The 16-in.-square objects used in the Florida tests had a reflectance of 7.5 percent and thus were considerably darker than the unfinished boards used in our tests which had a reflectance of approximately 36 percent.

TABLE 9

VISIBILITY DISTANCE DATA FROM AMA REPORT*

Observer	N_c	$\bar{X}_c$	σ_c	N_{ha}	X_{ha}	σ_{ha}	D	σ_d	Diff.	Probable Error
		ft.	ft.		ft.	ft.	ft.	ft.	%	%
Devine	30	250	28	30	235	33	15	8	6.0	±2.2
Boylan	30	310	34	32	280	33	30	9	9.7	±1.9
Besch	30	288	33	30	270	30	18	8	6.3	±1.9
Wagar	31	283	45	30	266	34	17	10	6.0	±2.5

*Subscript c refers to clear glass; subscript ha to heat-absorbing. For explanation of other symbols see legend.

The results in the present study show great variations in the effect of tinted glass on visibility distances as compared to clear glass. The greater part of the data obtained showed considerable reduction in visibility where the green glass was used, although there are several instances where the tinted glass gave higher readings than the clear glass. It does not appear feasible to assign an over-all percentage value to represent the difference between the two types of glass.

When the original tests were made, it was thought at first that the differences in percentage reductions were due to the size, color, and contrast of the different objects. The later tests, however, show the same extreme variations in percentage differences for a given observer, even though all objects used were practically identical. A study of the data fails to show a consistent relationship between percentage difference and any of the other recorded variables to account for the variations.

The use of tinted windshields appears to cause a reduction in visibility distances in night driving. Though the percentage difference between the types of glass appears small in some instances, the measured difference in seeing distance should not be lost sight of. Distances of from 10 to 70 ft. might easily mean the difference between striking an object and avoiding it.

It is recommended that the 70-percent-minimum luminous transmittance requirement for windshields in the American Standard Safety Code Z26.1-1950 be reconsidered in view of the present data.

The tests reported upon above were made under the best of roadway conditions and further tests are believed necessary to indicate the effect of tinted glass under adverse weather conditions. Effort should be made in future tests to rigidly control all known variables in the hope that reproducible results may be obtained on identical objects viewed by the same observer.

LEGEND

X = visibility distance in feet
N = number of observations
$\bar{X}$ = arithmetic mean of observations, $\frac{\Sigma X}{N}$, in feet
σ = standard deviation of observations, in feet

$$= \sqrt{\frac{\Sigma (X-\bar{X})^2}{N}}$$

D = difference between arithmetic means of clear glass and tinted glass visibility distances, in feet. Data are underlined where tinted glass values were greater than clear glass values.

σ_d = standard deviation of the differences between clear glass and tinted glass visibility distances.

$$= \sqrt{(\sigma_{\bar{X}_c})^2 + (\sigma_{\bar{X}_g})^2}$$

subscript c = values for clear glass
subscript g = values for green-tinted glass
subscript ha = values for heat-absorbing glass

Percent Difference $= \frac{D}{Xc} \times 100$

Percent Probable Error $= 0.675 \frac{d}{Xc} \times 100$

REFERENCES

1. American Standard Safety Code for Safety Glazing Materials For Glazing Motor Vehicles Operating on Land Highways. (Z26.1-1950.) American Standards Association, New York, N. Y., 1950.

2. Finch, D. M., Preliminary Report on The Effect of Tinted Windshields on Visibility Distances. (Intradepartmental Report.) Institute of Transportation and Traffic Engineering, University of California, June 1951.

3. Roper, Val J., Nighttime Seeing Through Heat-Absorbing Glass Windshields, 1952.

NIGHTTIME SEEING through HEAT-ABSORBING WINDSHIELDS

Val J. Roper, Illuminating Engineer
General Electric Company

SYNOPSIS

The glass used in heat-absorbing windshields currently available transmits 18 percent less light than ordinary windshields. This reduction in light transmission led to concern about the possibility of a serious reduction in nighttime-seeing distances, which are barely sufficient, at best.

Tests were conducted on an airstrip, using two identical cars equipped with sealed-beam headlamps. Ordinary and heat-absorbing windshields were interchanged in the two cars. Observations were made while driving at 40 mph., half with each type of windshield. Seeing-distance observations were made both against the glare of an approaching car and when the road was clear.

A summary of these observations shows an average reduction in seeing distance of not quite 6 percent for driving with no approaching vehicle and an average reduction of 2 percent when approaching another car on a straight, level road over a distance of almost a mile.

For the most critical portion of the seeing-distance curve, the last 500 ft. before meeting an approaching car, results show the same seeing distances through ordinary and heat-absorbing windshields. This may be explained by the slight reduction in brightness of the approaching headlamps as offsetting the reduction in brightness of the obstacles under observation. Both reductions are caused by the 18-percent additional absorption of light by the heat-absorbing glass.

As a result of these data, it may be argued that unless the driver does practically all of his driving at night, the daytime benefits to be derived from the heat-absorbing glass windshield offset the small reduction in seeing distance at night. This reduction averaged 3 percent over the entire seeing-distance curve obtained in the tests reported as a result of the investigation.

TWO types of heat-absorbing glass windshields are available for installation on motor vehicles. The lower portion of these windshields, through which one normally views the road, is essentially the same in both types. The heat-absorbing glass has relatively high iron content which effects an approximate 50-percent reduction in heat transmission, as compared to ordinary, clear glass windshields. The light transmission through this lower portion is reduced approximately 18 percent, as compared to that of clear glass windshields (see Figure 1).

This latter factor, the reduction in light transmission of 18 percent, caused some state administrators and others to express concern over the possibility of increased hazard in nighttime driving behind heat-absorbing windshields. They feared that seeing distances would be reduced materially, without compensating reduction in car speed.

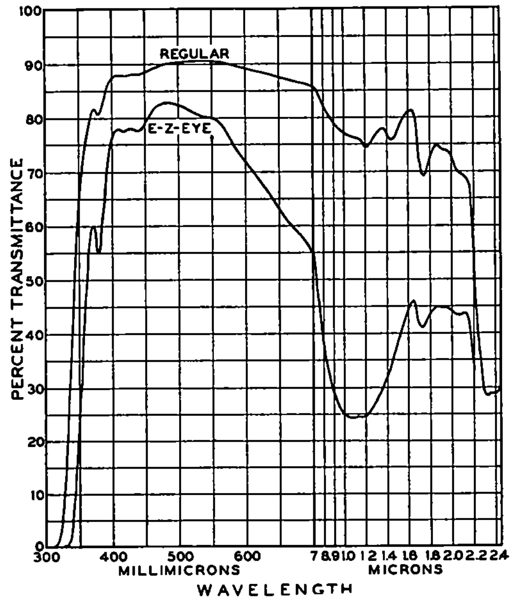

Figure 1. Spectral transmittance L.O.F. laminated plate glass thickness = 0.233 in.

Fortunately, the reduction in seeing distances is much less than the reduction in light transmission. Study of data from previously conducted seeing-distance tests (1), using headlamps of varied light output, indicated that the average reduction in seeing distance through the currently available heat-absorbing glasses should not exceed 5 percent. This is based on the assumption that the reduction in light transmission would have exactly the same effect as an equivalent reduction in beam candlepower from the headlamps.

Because of the general interest in the matter, it was decided to run some seeing-distance tests in the spring of 1951 to compare results with clear and tinted windshields. These were conducted at the General Motors Proving Grounds in April of 1951 by General Electric and Libbey-Owens-Ford. Six observer-drivers were used. The resultant data showed essentially the same seeing distances through heat-absorbing and clear glass windshields. However, it was admitted that an insufficient number of observations were made to be certain of an accurate statistical comparison. That is, the probable error in the observations was greater than the apparent difference in seeing distances through the two different types of windshields.

The increasing general interest of the public in the benefits of daytime driving in cars equipped with the heat-absorbing glass, the still-not-fully-satisfied concern of state administrators over the effects of higher light absorption, and the desire of car manufacturers and the glass manufacturers to resolve the issue, all combined to point to the desirability of conducting additional and conclusive tests.

It was decided that such tests should again be made using observer-drivers and with technique and instrumentation previously employed by

General Electric in seeing distance tests (2) with various types of head-lighting equipment, tests similar to those conducted previously but with more observations. This particular test procedure makes it possible to plot seeing-distance curves for the condition of approaching, meeting, and proceeding beyond another car on a straight,level, two-lane road. To eliminate all influencing variables, excepting that of the windshields (and seeing distances), the tests were conducted on a moonless, clear night with two identical cars, operating at identical speeds (40 mph.), equipped with identical, sealed-beam headlamps, and operated by the same two drivers throughout the tests.

There appears to be no reason to expect any difference in the relation of seeing distances obtained behind the two different windshields with drivers having less than normal visual acuity as compared to drivers having normal visual acuity. However to check this point the two drivers were selected as having 20/20 acuity by the AMA chart (one with spectacles). And additional observations were made with two passenger-observers who had 20/40 acuity.

The test obstacles were 16-in. squares of painted paper board having a reflectance of 7.5 percent. They stimulate the hazard presented by a small animal. Twelve of these were distributed ahead of and behind the meeting point, just off the right edge of the travelled roadway. Eleven of the obstacles on each side were gray in color. The twelfth (last) was red but of essentially the same reflectance (Figure 2).

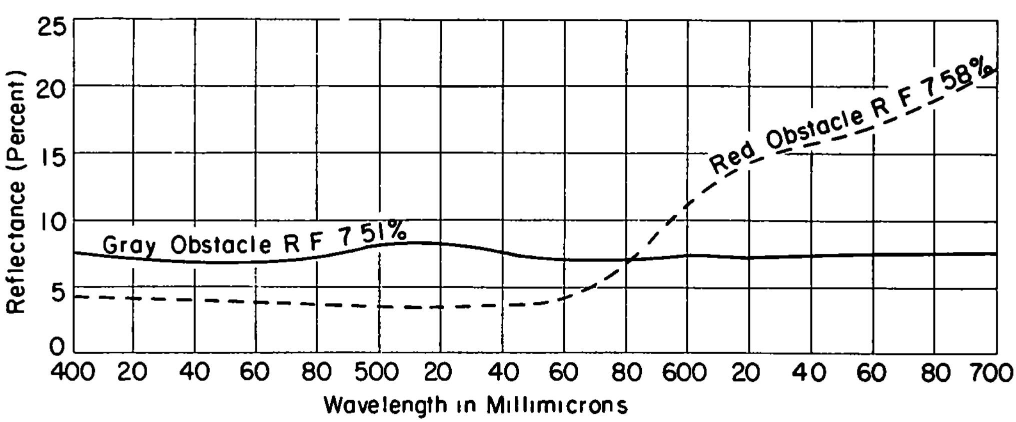

Figure 2. Spectral reflectance curves for 16-in. square obstacle test on heat-absorbing windshields.

Seeing distances were recorded by means of a paper-tape recorder (3) driven by a power takeoff from the transmission. The recorder had three marking pens, one connected through a relay to the horn ring, one to a switch held in the hand of the passenger-observer, and one to a switch held in the hand of a monitor riding in the back seat with the recorder.

The two cars were started at opposite ends of a 1.2-mi. stretch of the roadway. They started upon signal, accelerated to 40 mph. and held that speed for the entire test run. The drivers used the upper beams from their sealed beam headlamps until the two cars were 1,500 ft. apart, then depressed to the lower beams and continued to use the lower beams for the balance of the test run, even after passing the meeting point. This was done to effect a more critical seeing condition and to obtain lower seeing-distance values.

Upon perceiving each obstacle, the observer-driver depressed the horn ring, thus marking the tape on the recorder. (The horn was disconnected). Also, upon perceiving each obstacle, the observer-passenger pressed the switch which he held in his hand and which actuated a second pen on the tape. When the driver came abreast of each obstacle, the test monitor in the back seat pressed the switch he held in his hand, making a third impression on the tape of the recorder. The linear distance between the "pips" made by the driver and passenger and that made by the back seat monitor is the seeing distance. Twelve such seeing distance observations were recorded upon each individual test run, for each observer from each car. After six test runs, the windshields were changed. The purpose of changing so often was to avoid any possible influence of fatigue affecting readings through one of the windshields more than the other.

In order to plot the data in curve form as a function of the distance between the two cars, it is necessary to know exactly the distance between the two cars at the times of making the observations. This required maintaining uniform speed. A good check as to whether or not the uniform speed was maintained in any given test run was whether or not the two cars passed at exactly the half-way point. When they did not pass within approximately a car length of the half-way point, this test run was ignored.

The test location was an Air Force airstrip near Orlando, Florida. The time was late in February 1952. The surface was concrete in excellent condition. Two center lanes were used: the width of the two lanes was 22 ft. 4 in. The test obstacles were positioned at the outside edge of each lane. That is, they were just to the right of the travelled roadway. A total of 60 acceptable test runs were made, 30 for each windshield condition. This gave a total of 30 seeing-distance readings for each of the 12 obstacle positions with each windshield and for four observers: two drivers, two passengers. There were a total of 2,880 seeing-distance observations: 1,440 observations for each windshield condition (See appendix for sample procedure guide.)

All of the individual readings taken are plotted on Figures 3 through 10. Each of these figures also includes a single average curve drawn through the calculated statistical average for each obstacle location.

The 30 observations of each observer at each obstacle location were plotted on probability charts, from which the statistical averages were obtained. The average seeing distance of each obstacle for each observer and with each windshield is given in Table 1. The standard deviation for each is also included. Table 2 gives the percentage seeing distance of each obstacle in terms of 100 percent for the clear windshield.

A composite picture of the comparative results is given in Figures 11 through 14, which have the average curves for the heat-absorbing and clear

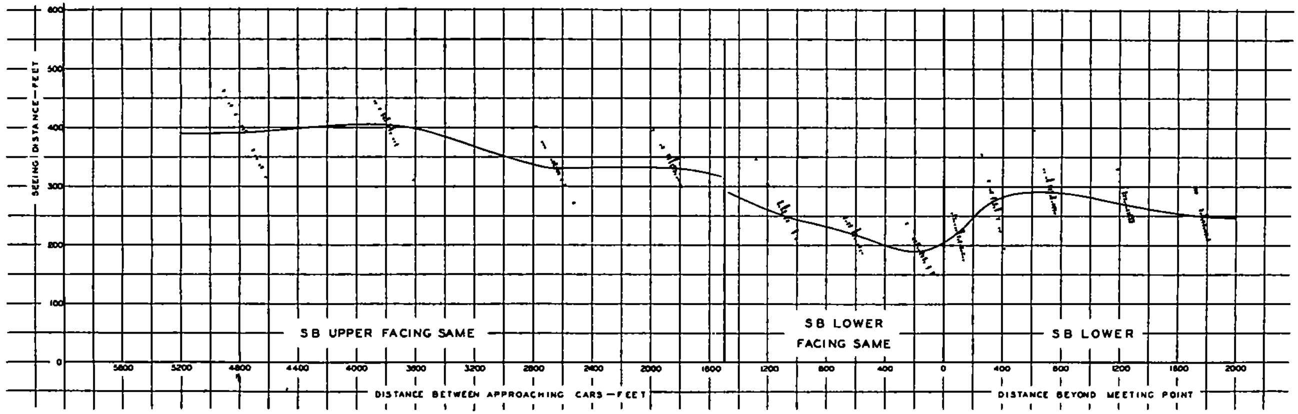

Figure 3. Clear windshield, driver-observer.

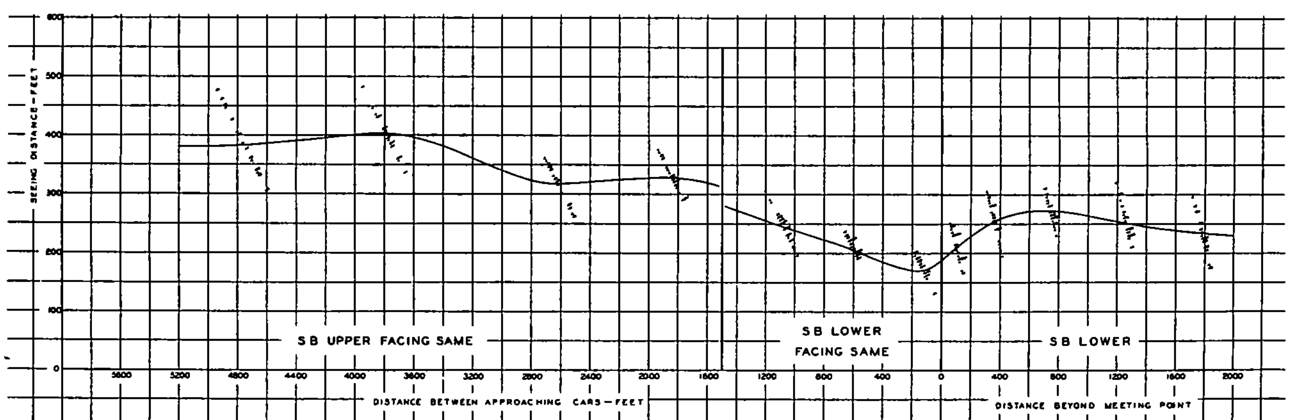

Figure 4. Heat-absorbing windshield, driver-observer.

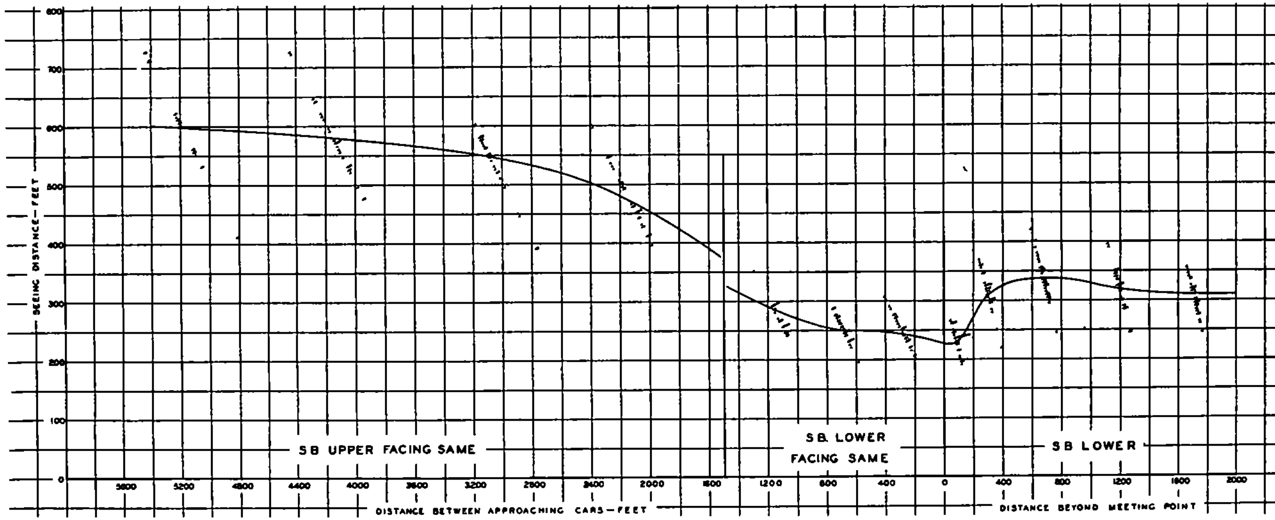

Figure 5. Clear windshield, driver-observer.

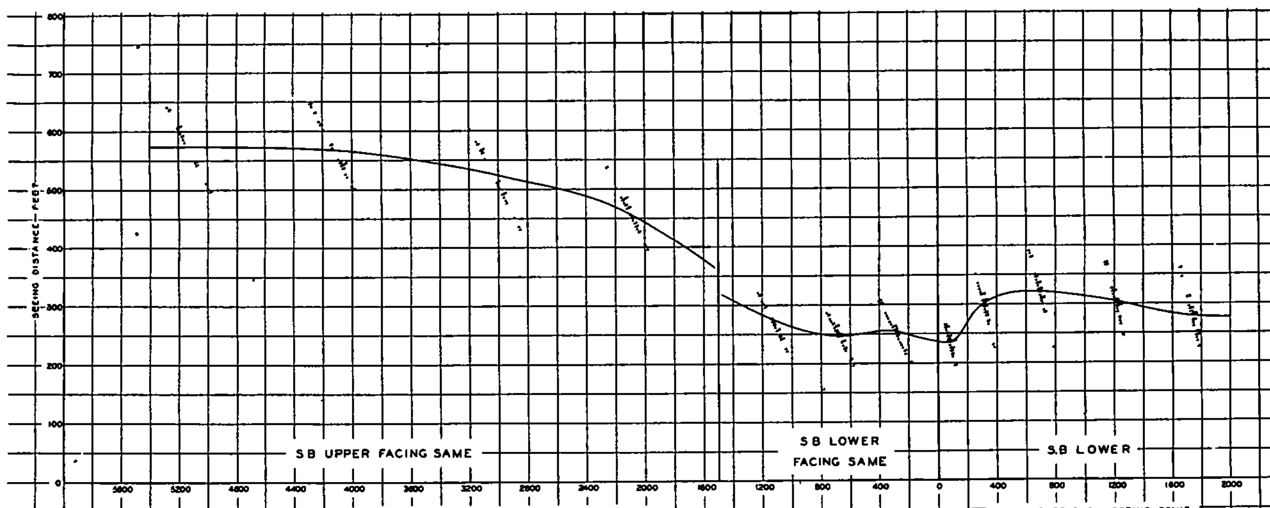

Figure 6. Heat-absorbing windshield, driver-observer.

windshields plotted together on the same graph. In terms of seeing through the clear glass windshield as 100 percent, the seeing distances through the heat-absorbing windshield varied from 90 to 104 percent.

TABLE 1

AVERAGE DISTANCE OF PERCEIVING OBSTACLES ($\bar{X}$)
AND STANDARD DEVIATION OF SUCCESSIVE TRIALS (σ)

		Driver				Passenger			
		Devine		Boylan		Besch		Wagar	
*		$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
20A	Cl.	391	55	599	75	473	58	436	56
	H.A.	382	57	572	72	477	63	402	61
15A	Cl.	405	29	580	62	468	53	412	49
	H.A.	403	45	568	60	468	54	400	42
10A	Cl.	331	32	548	83	429	69	422	83
	H.A.	317	39	526	64	415	66	410	76
6A	Cl.	332	27	474	54	381	46	370	42
	H.A.	328	29	460	42	373	37	337	47
3A	Cl.	251	37	286	47	276	49	244	28
	H.A.	246	27	278	36	278	41	234	26
1A	Cl.	221	21	250	23	247	18	214	15
	H.A.	208	15	246	29	247	20	209	21
1B	Cl.	189	31	244	37	333	32	225	32
	H.A.	170	25	255	33	333	22	240	39
3B	Cl.	217	26	227	25	246	16	215	21
	H.A.	208	32	236	21	244	14	221	19
6B	Cl.	274	46	307	36	303	36	260	28
	H.A.	252	39	299	31	291	32	246	36
10B	Cl.	291	24	337	37	334	45	279	30
	H.A.	273	24	322	35	303	36	262	31
15B	Cl.	269	26	320	38	300	33	270	35
	H.A.	252	31	306	33	287	36	265	37
20B	Cl.	250	28	310	34	288	33	283	45
	H.A.	235	33	280	33	270	30	266	34

*Hundreds of feet ahead and behind meeting point.

There appears to be no significant difference in the comparative results with the driver-observers and passenger-observers, although the data do show a considerable variation in the ability of the individual observers to see at night.

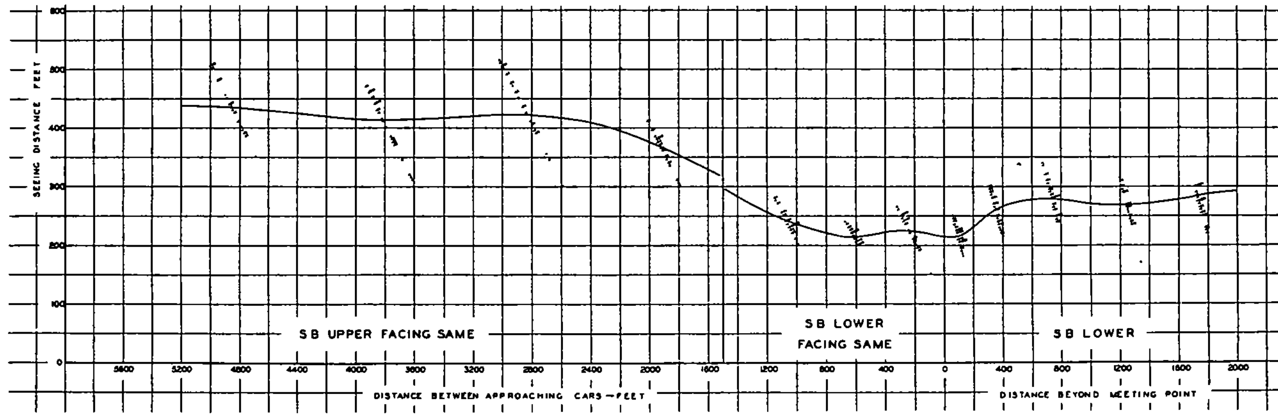

Figure 7. Clear windshield, passenger-observer.

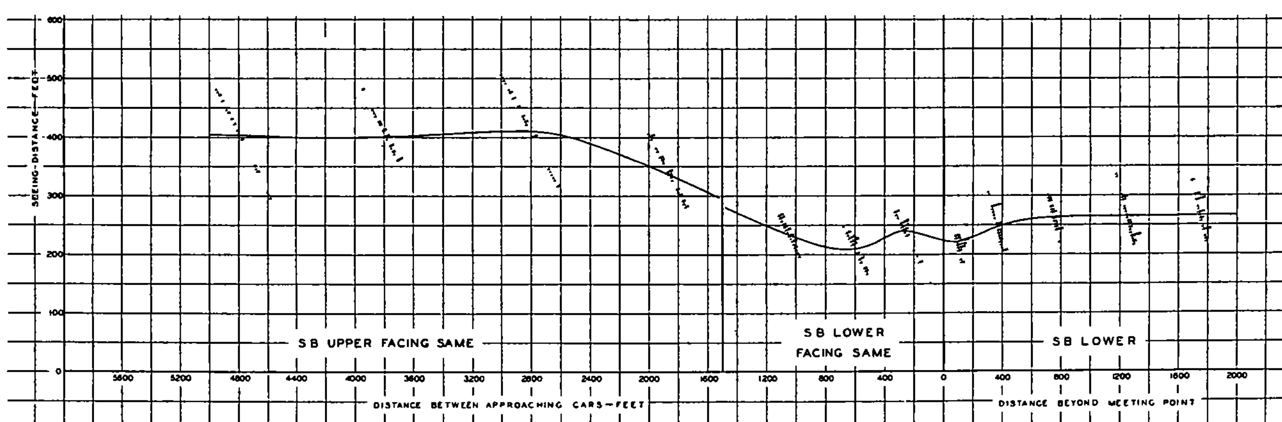

Figure 8. Heat-absorbing windshield, passenger-observer.

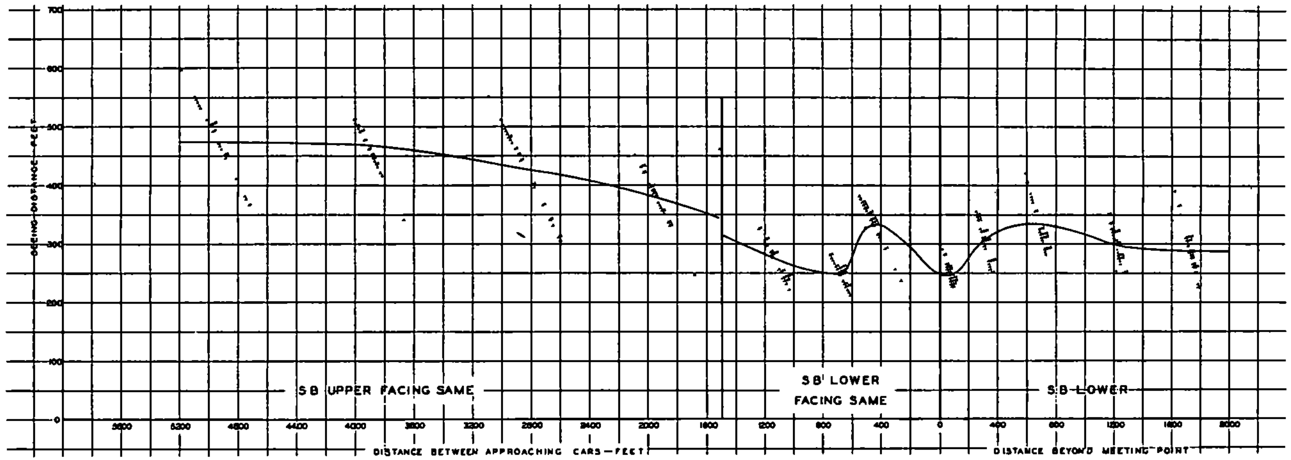

Figure 9. Clear windshield, passenger-observer.

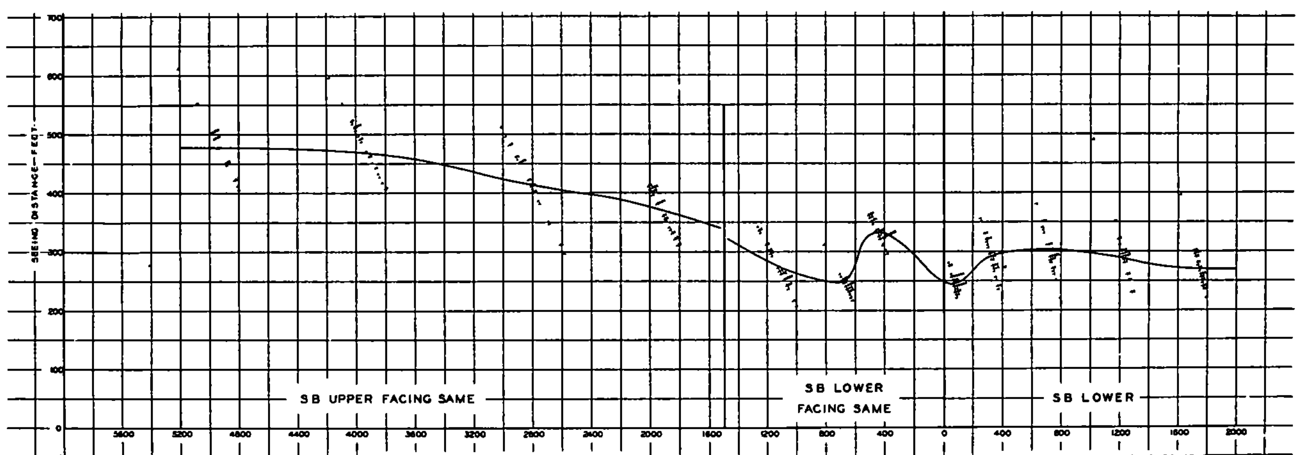

Figure 10. Heat-absorbing windshield, passenger-observer.

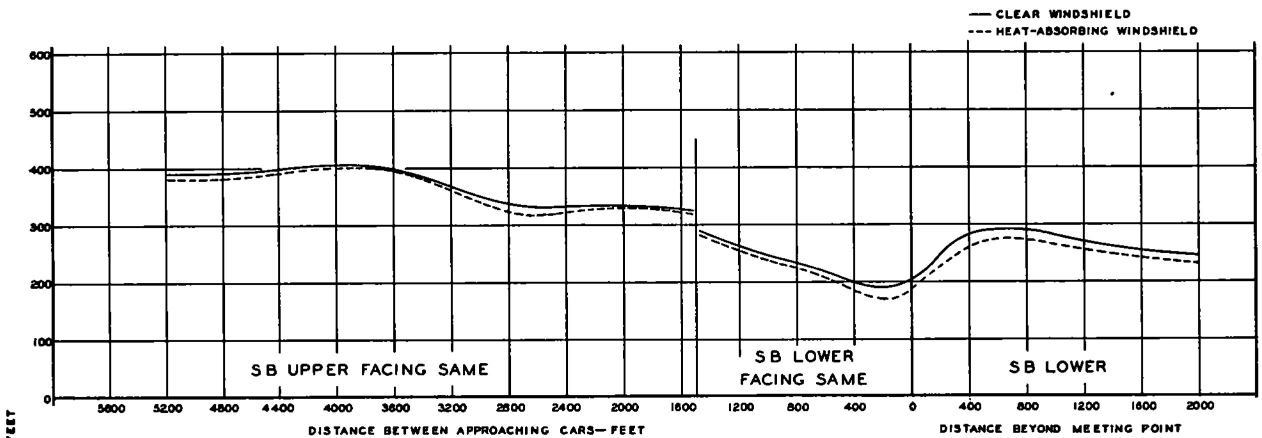

Figure 11. Driver-observer.

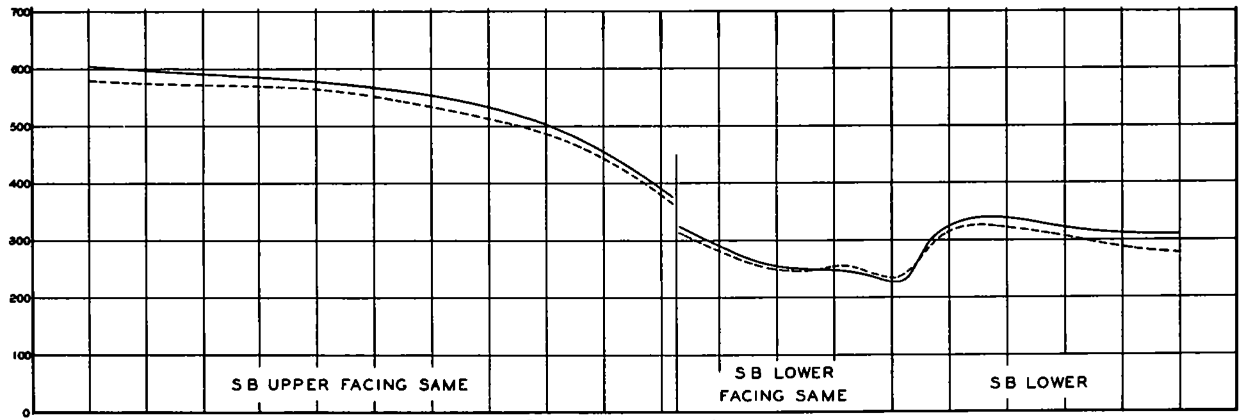

Figure 12. Driver-observer.

TABLE 2

SEEING DISTANCES PERCENT HEAT ABSORBING OF CLEAR WINDSHIELD

*	Devine	Boylan	Averages Besch	Wagar	Average
20A	97.7	95.5	100.8	92.2	96.55
15A	99.5	97.9	100.0	97.1	98.62
10A	95.8	96.0	96.7	97.2	96.43
6A	98.8	97.0	97.9	91.1	96.20
3A	98.0	97.2	100.7	95.9	97.95
1A	94.1	98.4	100.0	97.7	97.55
1B	89.9	104.5	100.0	106.7	100.28
3B	95.9	104.0	99.2	102.8	100.47
6B	92.0	97.4	96.0	94.6	95.00
10B	93.8	95.5	90.7	93.9	93.48
15B	93.7	95.6	95.7	98.1	95.78
20B	94.0	90.3	93.7	94.0	93.00
Avg.	95.27	97.44	97.62	96.78	96.78

*Hundreds of feet ahead and behind meeting point.

The average loss in seeing distance with the heat-absorbing windshield is somewhat less for that portion of the curve involving an opposing vehicle, especially within the last 1,500 ft. before meeting. This may be explained by the 18-percent reduction in brightness of the opposing headlamps viewed through the heat-absorbing windwhield as compared to the regular windshield. This reduction in glare, although too slight to be noticeable, does counteract to some extent the reduction in obstacle brightness. For what might be termed the most-critical portion of this seeing-distance curve, that portion providing the least seeing distance, there is little reduction effected by the heat-absorbing windshield. The average reduction for all obstacle positions involving opposing headlamps was 2 percent. The average reduction for those obstacle positions involving clear road driving was 5.7 percent. The over-all average of all the readings through the clear windshield was 325 ft., of those through the heat-absorbing shield, 315 ft. A single composite graph of the average of all observers is given in Figure 15.

These data prove that the difference in nighttime-seeing values through the heat-absorbing windshields currently available and standard glass windshields is, indeed, much less than the additional light absorption of the heat-absorbing glass.

You will observe a break in each average seeing-distance curve at the point where the two cars are 1,500 ft. apart. This is the point at which both cars shifted from the sealed-beam upper beam to the sealed-beam lower beam. It was somewhat in advance of the optimum point for depressing the beams, which according to previous data (4) is on the order of 1200 ft. with sealed-beam headlamps. This explains the immediate drop in seeing-distance values.

In actual practice, the seeing distances would be considerably less than those obtained in this test. These observer-drivers knew the test

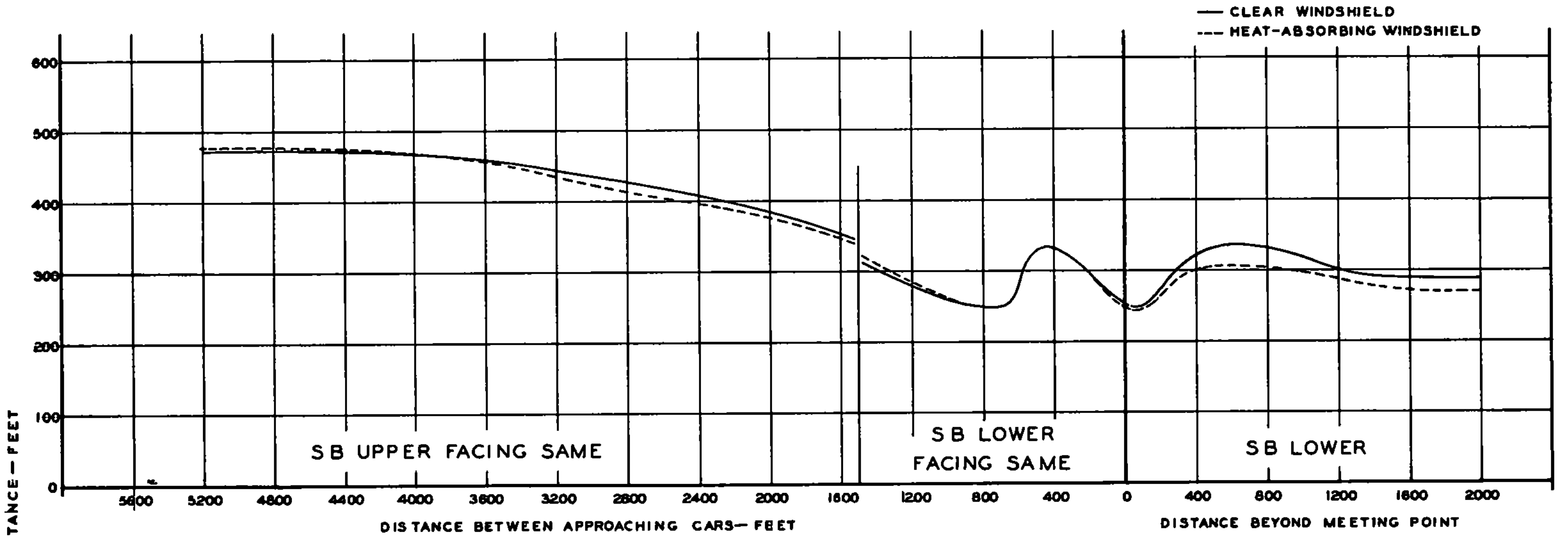

Figure 13. Passenger observer.

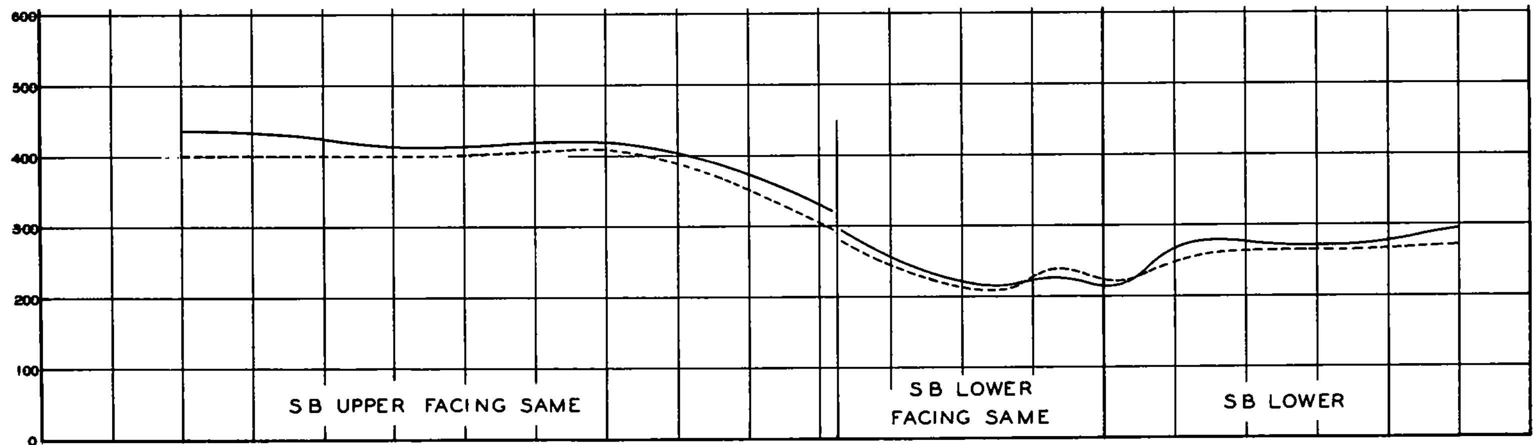

Figure 14. Passenger-observer.

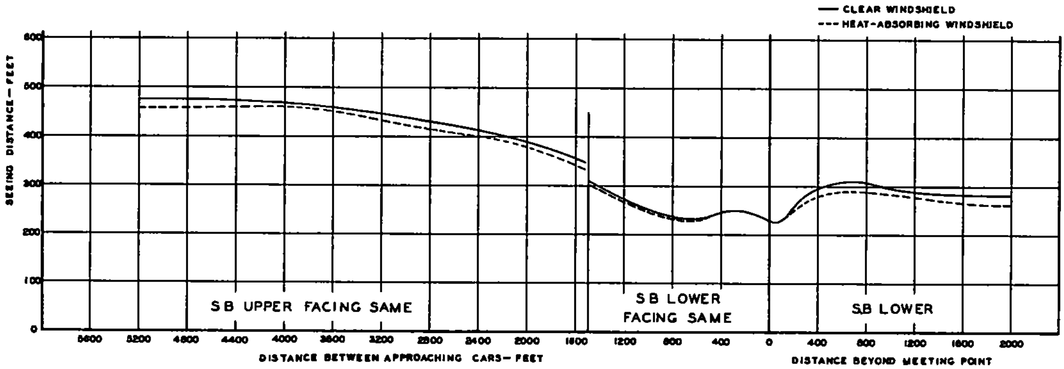

Figure 15. Average of four observers.

obstacles were there and where to look for them. Therefore, they were displaying more than normal attention, and obtained seeing-distance values higher than those which would be normal in ordinary driving (1, 2). It follows that state administrators were properly concerned about any change which reduced nighttime-seeing distances. For at best, these are none too good. The car manufacturers were, of course, equally concerned about the situation and, from the information available at the time of introduction of heat-absorbing glass windshields, were of the opinion that the reduction in light transmission was not sufficient to offset their daytime advantages. The results of the Orlando test can be interpreted to justify this position.

VISIBILITY ON LIGHTED STREETS*

Direct measurements of relative visibility, comparing windshields of regular, clear glass and heat-absorbing glass, were made on lighted streets. There were 3 observers, S. K. Guth, A. A. Eastman, and R. C. Rodgers, all of the Lighting Research Laboratory at Nela Park. These observers took readings simultaneously from the front seat of a test car, using Luckiesh-Moss Visibility Meters. The test object, of which relative visibility measurements were made, was a 12-in. disk, of 8 percent reflectance, in a vertical position at street level, 200 ft. in front of the test car. This technique of measurement had been employed by Reid and Chanon (5, 6) in earlier studies of factors affecting visibility on lighted streets.

Measurements were made under three street-lighting systems. These lighting systems conformed to standards of the American Standard Practice for Street and Highway Lighting (7) for street classifications of local traffic, light traffic, and medium traffic, respectively. On each street were four test stations, uniformly spaced between street lamps. At each station measurements were made first with one type of windshield then with the other. The sequence was reversed at successive test stations. The test car, with readily replaceable windshields, was provided by H. C. Doane of Buick.

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*Contributed by Kirk M. Reid, Illuminating Engineer, Lamp Division, General Electric Company, Cleveland.

The average of all measurements showed a relative visibility with the heat-absorbing windshield approximately 2 percent below that with the clear windshield. Measurements under each of the lighting systems conformed to this average, within reasonable variations.

The heat-absorbing windshield with a darkened strip near the top gave best results when the darkened strip reduced the veiling glare from one or more of the nearby street lamps. This took place at some stations, depending on the height and posture of the observer. At such stations the visibility with the heat-absorbing windshields was fully equal to that with the clear windshield. Under other conditions the differential in favor of the clear windshield was somewhat greater than the overall average of 2 percent.

ACKNOWLEDGMENTS

The test cars used were furnished by the Buick Motor Division of General Motors. The observer-drivers were A. W. Devine, assistant registrar of the state of Massachusetts, and Henry W. Boylan, Experimental Engineering Department, Buick Motor Division. The observer-passengers were Emil Besch, assistant supervisor, Chemical Laboratories, Chrysler Corporation, and T. E. Wagar, chief electrical engineer, Studebaker Corporation. The test monitors were Val Roper and Glen Pracejus of the General Electric Co., Nela Park, Cleveland. H. C. Doane, assistant chief engineer, Buick Motor Division, served as chairman of a committee of the Automobile Manufacturers Association charged with organization for the test. Also present as consultants and observers were George E. Keneipp, director of vehicles and traffic for the District of Columbia and chairman of the Committee on Engineering and Vehicle Inspection of the American Association of Motor Vehicle Administrators; Rudolph F. King, registrar of the state of Massachusetts; W. F. Sherman, manager, Engineering and Technical Department of the Automobile Manufacturers Association; T. F. Creedan, field representative, Automobile Manufacturers Association; Bruce G. Booth, of the legal staff of General Motors; and Don Munroe, of Chemical Laboratories, Chrysler Corporation.

The authors are also indebted to W. H. Abbott, expert statistician at G. E.'s Nela Park, for his statistical analyses of the 2,880 observations; to Byron F. King, Orlando Buick dealer, for the arrangements with the Airport; and to Col. James E. Roberts, Pine Castle Base Commander, who provided the facilities at the Pine Castle Airport, Orlando, Florida.

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APPENDIX

Heat-Absorbing Windshield
Orlando (Fla.) Tests

Procedure, February 26, 1952

SIGNALS - Control Car A signals by turning upper beam on and off twice.
Then turn lights off and wait for reply signal.
Car B uses same signal in reply.
Car A turns lights on and starts.
Car B does likewise.

SPEED - 40 mph.

LIGHTS - Cars start on upper beam, 6,000 ft. apart. Depress beams at red lantern when cars are 1,500 ft. apart. Continue to end of run on lower beam. Raise to upper beam and turn around for next run. Turn lights out at starting point.

TEST RUNS - Each run to be numbered consecutively. Bad runs to be noted on log sheet (no signal to other car). Run numbers to be put both on the test tape and on the log sheet. Also note car number on each. When run is rejected, note and explain on log sheet. Each car to report at north end whether runs are good or bad, and reason. Controller at north end will note and advise time for windshield change.

MATERIAL - Start with clear glass and make enough runs to get six good ones. Change to heat-absorbing glass (no tint in upper part) and get six good runs. Repeat.

RECALL SIGNAL - Spotlight flashed in air.

DEVELOPMENT of the GUIDE "AUTRONIC EYE"

G. W. Onksen, Research Engineer
General Motors Corporation

SYNOPSIS

Headlamp glare has been a problem since headlamps have been used on automobiles. Over the years, headlamps have been standardized and improved until now the glare problem is largely a matter of improper usage. Many drivers use their headlamp beams improperly; some do not depress to the lower beam when meeting another car; and others drive continuously on their lower beam. It has not been possible to get drivers to use their beams properly.

An automatic headlamp-control device offered possibilities for solving the glare problem. However, the variations in the brightness of headlamps between upper and lower beams made the outlook very discouraging, but the promise of real improvement in the glare situation forced the development in spite of difficulties. Early in the development, the problem was to make something sensitive enough to dim for lower beams at a safe distance. As sensitivity was increased, other problems in the fields of electricity and optics had to be solved. Gradually, the desirable characteristics of an automatic headlamp-control device became apparent.

The device should: (1) switch to the lower beam promptly when subjected to sufficient light and should switch back to the upper beam promptly when light is removed; (2) retain the lower beam when the approaching driver dims; (3) dim for cars on curves and should not dim excessively for extraneous light at the roadside; (4) not be affected by variations in the reflectivity of road surfaces; (5) function under conditions of adverse weather, such as rain, snow, and fog; (6) provide the driver with a means of obtaining a lower beam for use in the city and when following another car, when there is insufficient light to retain the lower beam automatically; (7) provide the driver with a means of obtaining an upper beam for signaling and at dusk, when there is too much light for the device to switch to the upper beam automatically; (8) function with normal variations of car loading; (9) provide the lower beam during warm-up; (10) not be impaired when operated in the daytime; (11) be insensitive to changes in battery voltage; (12) use a minimum of current to avoid exceeding the generator capacity; (13) withstand the abuses of automotive service which includes heat, cold, vibration, and moisture; and (14) be easily adjustable in the field.

The Guide "Autronic Eye" complies with all of these requirements and experience during the first year of production demonstrates that it offers real possibilities for solving the glare problem.

HEADLAMP glare has been a continuing problem ever since electric headlamps have been used on automobiles. A beam which illuminates the road far ahead for safe driving is too bright for the approaching driver. At first we had only one beam, and a resistance was switched in and out of an electric circuit to make the beam dim for approaching cars. Later we had headlamps with two beams: an upper beam designed for clear road driving and a lower beam designed to reduce glare when passing. As the years passed, headlamps were standardized and improved in accuracy, and inspection and service facilities were developed until now the glare problem is largely a matter of improper headlamp usage. However, conditions change so rapidly during open road driving that the correct choice of beam calls for rather careful attention on the part of the driver. All drivers are not willing to devote that much attention to the job. A few drivers do not dim until they are signaled, and many drive constantly on their lower beams to avoid using the foot switch. Both habits are dangerous. Experience indicates that it is hopeless to get drivers to pay more attention to their driving, either through education or law enforcement.

Even 15 or 20 years ago it was obvious that automatic headlamp-control devices offered possibilities for solving the glare problem — if they could be made to function properly. The outlook was far from encouraging when we consider that the brightness of an oncoming upper beam would, of course, be many times that of an oncoming lower beam, not to mention the added variation due to deterioration in pre-sealed-beam lamps. Even so, the promise of real improvement in glare was so obvious that the idea of automatic headlamp-control could not be ignored, no matter how hopeless it might look.

At the start, the problem was to develop something that was sensitive enough — something that would dim for lower beams at a safe distance. Satisfactory sensitivity was achieved by using a multiplier phototube, which is capable of about a million times the sensitivity of standard vacuum phototubes. As sensitivity was increased it was found that extreme variations in brightness of oncoming headlamps was not nearly as serious as anticipated, because very few roads are straight and level for any great distance. However, as sensitivity was increased, other problems in the fields of electricity and optics had to be solved. Gradually the desirable characteristics of an automatic headlamp-control device became apparent and were incorporated.

Figure 1 shows the circuit diagram of the "Autronic Eye" ("Autronic Eye" is Guide's trademark for an automatic headlamp-control device). Energy is provided by the car electrical system through the standard light switch. This voltage is applied through the fuse and the ballast tube to the primary winding of the transformer and then through a vibrator to the ground. The transformer has two secondary windings, one producing approximately 1,150 volts AC and the other approximately 150 volts AC. The higher voltage is rectified to produce approximately 1,000 volts DC across a load-resistor network. A high-voltage control is adjusted to supply the necessary voltage for the phototube unit. A sensitivity control in the phototube unit adjusts the high voltage to compensate for variations in phototubes. The voltage is applied to the various dynodes in the phototube through a voltage divider network.

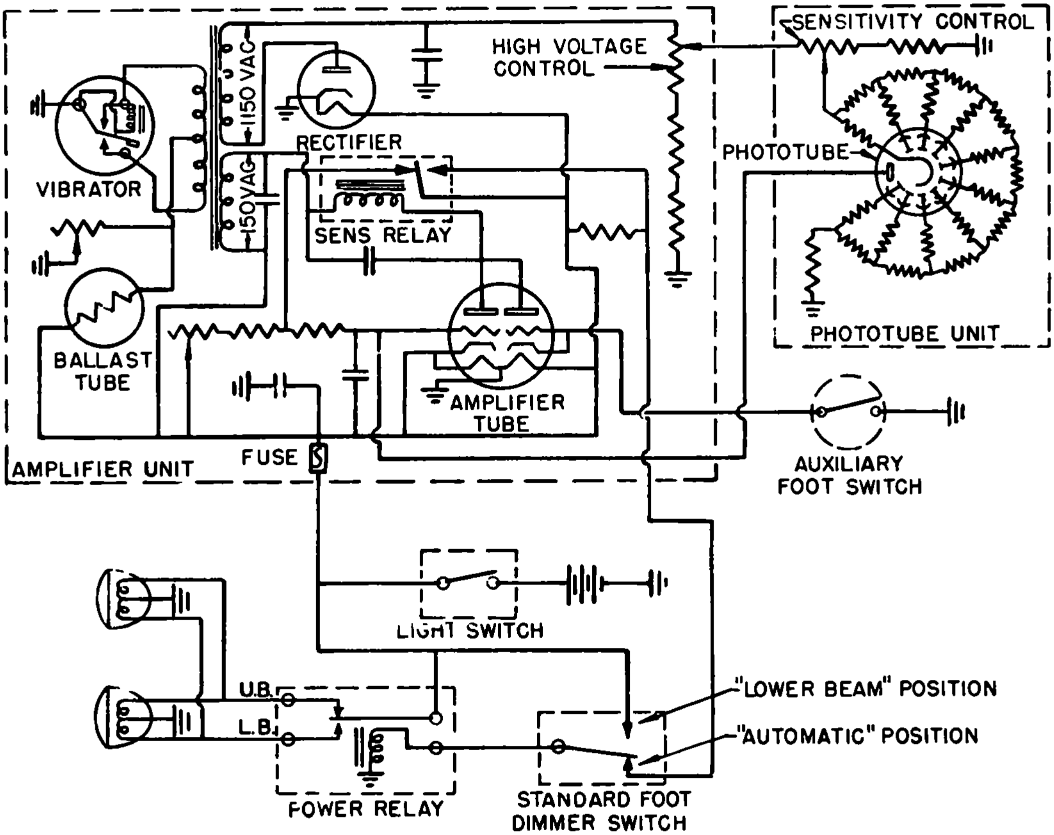

Figure 1. Circuit diagram of Autronic Eye.

The 150-volt secondary winding of the transformer supplies power for the amplifier tube and the sensitive relay. In the absence of light on the phototube, the amplifier tube passes enough current through the sensitive relay to close it. Light causes the phototube to pass a current through a load resistance which develops a negative bias voltage on the amplifier-tube control grid. This causes the amplifier tube to reduce the current through the sensitive relay. When the current is reduced sufficiently, the sensitive relay opens. When the sensitive relay opens it switches a much larger load resistance into the phototube circuit and, in this way, causes the device to be about 10 times as sensitive in the lower-beam position as it is in the upper-beam position.

When the standard dimmer foot switch is in the "Automatic" position, the sensitive relay opens and closes the power relay which switches the headlamps between the upper and lower beams.

When the push-button-type auxiliary foot switch is depressed, it closes the sensitive relay through an added section in the amplifier tube, and overrides the automatic control to provide the upper beam, even when bright light is on the phototube.

When the standard dimmer switch is depressed and released, as in changing from upper to lower beam, the power relay is closed directly from the light switch and holds the headlamps on the lower beam regardless of the position of the sensitive relay.

Figure 2 shows the optical design of the phototube unit. A condensing lens focuses light through an amber filter and through an opening in a mask to a multiplier phototube. The condensing lens is corrected for spherical aberration and focuses the light from approaching headlamps to a point in the plane of the mask. The vertical and horizontal angles through which the device responds to light are limited by the size of the opening in the mask, and the sensitivity cuts off abruptly when the point of focused light passes the edge of the mask opening.

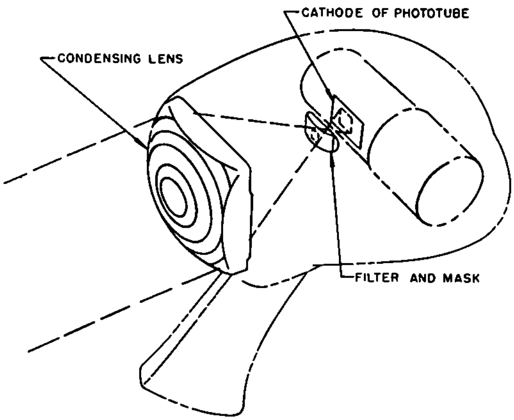

Figure 2. Optical design of phototube unit.

The multiplier phototube is manufactured with an S4 (blue-sensitive) cathode surface, because red-sensitive surfaces are not compatible with the materials used in the amplifying sections. However, the high sensitivity of the multiplier phototube permits the use of an amber filter, which absorbs blue light and moves the effective response toward the red end of the spectrum. Figure 3 shows a series of color-sensitivity and emission curves of the S4 cathode surface, the amber filter, an incandscent bulb, skylight, and the S4 surface through the amber filter.

The curves show that the relative emission of skylight is much better than from an incandescent bulb near the violet end of the spectrum while the incandescent bulb is better near the red end. The curves also show that the amber filter blocks off the light near the violet end and, thus, reduces skylight much more than incandescent light. The amber filter permits the device to function sooner at dusk by reducing the effect of skylight.

The "Autronic Eye" automatic headlamp-control device embodies a number of characteristics which are the result of years of development and testing. A discussion of these characteristics which are desirable in any automatic headlamp-control is as follows:

1. The device should switch to the lower beam promptly when subjected

to sufficient light, and should switch back to the upper beam promptly when light is removed.

There are occasions when the approaching car comes suddenly into view, as, for example, over the crest of a hill. At such times rapid dimming is important. Then, after passing a car when the road ahead is dark it is important to regain the upper beam promptly.

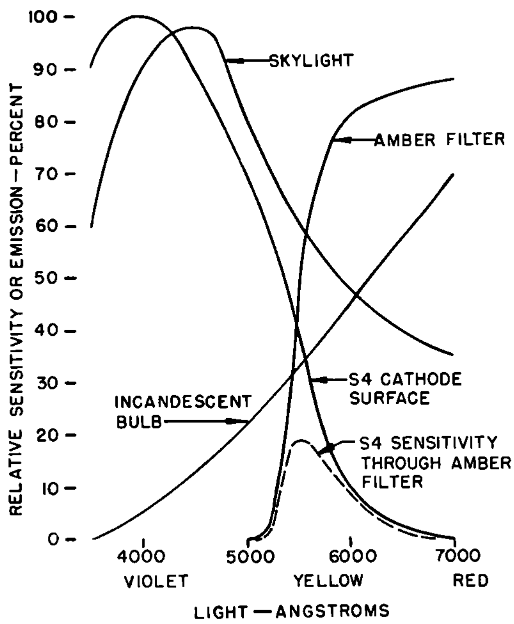

Figure 3. Color-sensitivity and emission curves.

2. The device should retain the lower beam when the approaching driver dims.

When the approaching driver switches to his lower beam the light on the phototube is greatly reduced. The device must not switch back to its upper beam in such a situation. The "Autronic Eye" was designed to dim for one sensitivity and then retain the lower beam with about 10 times as much sensitivity. The multiplier phototube provided the sensitivity for this technique and at the same time permitted rapid operation in both the dimming and upper beam recovery cycles.

3. The device should dim for cars on curves but should not dim excessively for extraneous light at the roadside.

The desire for dimming on curves conflicts with the desire to restrain the device from dimming for extraneous light at the roadside. The first desire would be satisfied by making the device responsive to light at wide angles to the sides while the second desire would demand that the device must not be sensitive to side light. Guide's automatic headlamp-control represents a compromise between these two conditions, designed to provide the narrowest possible sideways response angle consistent with proper operation on curves.

4. The device should not be affected by variations in the reflectivity of road surfaces and the device must function with normal variations of car loading.

Headlamps illuminate the road ahead and the road brightness reflecting back to the driver varies from almost nothing from wet asphalt to a considerable amount from dry gravel or fresh snow. A device which is sensitive enough to retain the lower beam after the approaching driver dims would necessarily be sensitive enough to be greatly affected from road reflection, unless the downward response angle was carefully controlled. If too much light from the road is permitted to reach the phototube, the device will stay on the lower beam. At the same time, the sensitivity response angle must extend enough below horizontal so that the device will function properly under conditions of normal car loading. Guide's unit has a lens and mask system which provides a sharp, lower cut-off. The cut-off is aimed as low as possible without incurring interference from road reflection. This aim is low enough to stand the upward tilting caused by normal car loading without undue loss in sensitivity.

5. The device should function under conditions of adverse weather such as rain, snow, and fog.

The light from approaching cars is somewhat diffused by rain on the windshield, but fortunately the device is not affected appreciably in sensitivity. There seems to be an increase in light from the approaching car, probably due to reflections from wet pavement adding to the normal direct light coming from the lamps and this may offset any loss from light diffusion. Drivers are particularly appreciative of the device in bad weather, because their attention can be concentrated on driving without having to pay attention to their headlights. Very little sensitivity is lost in moderate snow and fog. If the snow or fog is severe, the back reflection of the vehicle headlamps from the snow or fog particles is sufficient to retain the vehicle headlamps on the lower beam.

6. The driver should be provided with a means of obtaining a lower beam for use in the city and when following another car, when there is insufficient light to retain the lower beam automatically.

Occasionally, it is desirable to obtain a lower beam when there is not sufficient light ahead to retain the lower beam automatically. The amber filter previously referred to corrects, as much as possible, the relatively poor red sensitivity of the multiplier phototube. With this combination, the device will retain the lower beam satisfactorily when following a modern car with relatively bright tail lights, but it will not retain the lower beam at a sufficient distance for many older tail lights, and it will not dim for any of them. The "Autronic Eye" is connected to the standard dimmer foot switch so that it functions automatically in one position only. The other position of the dimmer switch provides a fixed lower beam. When necessary, the driver may use the foot switch to lock the device on the lower beam. One of the times when a continuous lower beam is desirable is when following another vehicle.

7. The driver should be provided with a means of obtaining an upper

beam for signaling and at dusk, when there is too much light for the device to switch to the upper beam automatically.

After the automatic headlamp control has dimmed, very little light is required to retain the lower beam. There are occasions, particularly from skylight at dusk, when there is sufficient light to retain the lower beam but not enough to cause the device to dim. On such occasions, the driver may prefer the upper beam. Guide's automatic headlamp control includes a push-button auxiliary foot switch to override the automatic control and provide the upper beam regardless of light conditions. This switch resets the sensitive relay to the upper beam position and the device will remain on the upper beam when the foot switch is released unless there is sufficient light ahead for dimming. Also, the overriding switch may be used to signal approaching drivers if they forget to dim.

8. The device should provide the lower beam during warmup.

Most electronic devices require a moderate warmup time, and during this period, they do not provide automatic control. This period of no control should be considered in design, because vehicles will usually be operated in areas of opposing traffic during the warmup period and it is desirable to have a fixed lower beam until the automatic control is functioning. Guide's device requires 10 to 15 sec. warmup time for the rectifier and amplifier tubes. The rectifier tube controls the high voltage to the phototube, and the amplifier tube provides the current to the sensitive relay. The sensitive relay is in the lower beam position when the amplifier tube current is "off." The rectifier tube was adjusted to warm up ahead of the amplifier tube so that the phototube is in control before the amplifier tube can operate the sensitive relay to the upper beam position.

9. The device should not be impaired when operated in the daytime.

Most phototubes, particularly multiplier phototubes, must be protected from damage from bright light. A multiplier phototube can easily destroy itself if it is permitted to pass too much current. We must assume that a driver will occasionally operate his automatic headlamp control during the daytime. There are places, for example, through the tunnels on the Pennsylvania Turnpike, where a driver is requested to turn on his headlamps in the daytime. It is common to see cars travel a considerable distance beyond the tunnel before their lights are turned off. The device is connected to be turned on with the headlamps so the phototube is functioning during this period. The dynodes of the multiplier phototube are connected through individual protective resistors so that the current through each dynode is limited to a safe value. These protective resistors do not affect the multiplier phototube function at night because the current values are too small to cause detrimental voltage changes to the dynodes.

10. The device should be insensitive to changes in battery voltage.

Car battery voltages vary from 5.5 to 7.5 volts, which is ± 15 percent from the midpoint. Multiplier phototubes are very sensitive to voltage changes; in fact, a 10 percent increase in voltage will double the output. In order to obtain satisfactory performance on a car, the "Autronic Eye" had to be designed with voltage regulation. Regulation was obtained by using a current regulator (ballast tube) in the primary of the transformer. Table 1 shows the sensitivity with variations in battery voltage. The dimming distance varies from about minus 7 percent to plus 2 percent.

TABLE 1

VARIATIONS IN SENSITIVITY WITH CHANGES IN BATTERY VOLTAGE

Voltage	Percent Sensitivity (Dimming Distance)
5.5	93
6.0	100
6.5	100
7.0	102
7.5	102

11. The device should use a minimum of current to avoid exceeding the generator capacity.

Car generators are designed to keep the batteries charged under given load conditions; and ordinarily they will not accommodate much extra load. For this reason, the device should be designed to use a minimum of current. Guide's automatic headlamp-control device uses 2.1 amperes in the upper-beam position and 2.5 amperes in the lower-beam position.

12. The device should withstand the abuses of automotive service which includes heat, cold, vibration, moisture, and dust.

Extensive field testing and tests on the Belgium Block road at the General Motors Proving Ground indicated that special precautions were required to make the automatic headlamp control rugged enough for automotive service. The chassis was reinforced and condensers were anchored to avoid wire breakage. A special lead construction was used in the vibrators to avoid internal wire breakage. High-temperature condensers were used because of high engine heat on hot days. The amplifier was enclosed to protect it from moisture and dust. Special alloy points were used on the sensitive relay to avoid tarnish. Special alloy points were used on the power relay to handle the headlamp load. Special materials were used in the phototube base to avoid electrical leakage due to moisture. Experiences with the "Autronic Eye" indicate that extensive tests on cars are required to locate and correct weaknesses in devices of this nature.

13. Service facilities should be available to adjust the device in the field.

An automatic headlamp control is basically a light-measuring device. It dims with a particular amount of light and switches back to the upper beam with a much smaller amount of light. The value of light at each operating point is important and must be obtainable in the field for service adjustments. Also, the phototube unit should be aimed. The lower edge of the response angle is particularly important. Two pieces of test equipment were developed for servicing Guide's automatic headlamp control: a test lamp for sensitivity adjustments and an aiming device for aiming the phototube unit. The test lamp projects light against the phototube in about the same manner as headlamps under operating conditions. The brightness of the test lamp is adjusted to specific values by means of a meter - one brightness is used to adjust "dim" sensitivity and a different brightness is used in making "hold" sensitivity adjustments (this is the point where the device switches back to the upper beam.) The aiming device is a mechanical fixture which aims by means of a level. The fixture sets on top of the phototube unit and it has an aiming dial which is adjusted to a code number stamped on a nameplate underneath the phototube unit. The code number adjusts the position of the level to compensate for variations between the top surface of the phototube unit and the lower edge of the response angle. The code number is stamped at the factory. The bottom edge of the response angle is located in an optical fixture by means of test lights and then a master level is placed on the phototube unit to find the code number. In this manner, an optical aim of the response angle is converted at the factory into a mechanical aim, and then the mechanical aim is used for field service. Due to the high sensitivities required in automatic headlamp-control devices, satisfactory operation is largely a matter of proper adjustment so the importance of adequate field service facilities cannot be overemphasized.

CONCLUSION

The Guide "Autronic Eye" complies with all of these requirements, and experience during the first year of production demonstrates that it offers real possibilities for improving the glare problem. Public acceptance has been unusually good, particularly since an owner's first thought is that he is spending money for a device which only benefits the other fellow. However, he quickly learns that the device does even more for him than for the approaching driver. He finds that the device gives him an upper beam more often than ever before in spite of the fact that it always dims for approaching cars. By relieving the driver of the burden of operating his headlamps, the "Autronic Eye" makes night driving more pleasant and safe.

DESIGN of the MEETING BEAM of the AUTOMOBILE HEADLIGHT

A. J. Harris
Road Research Laboratory
Harmondsworth, England

SYNOPSIS

The most-important factor in the design of the typical meeting beam, 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 (i.e., of being rendered incapable of seeing more than 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 the sharpness of cutoff required to give any desired level of freedom from dazzle, or glare. It is shown that if the 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.

HEADLIGHT beams must be judged by their performance in the conditions in which they have to operate: meeting beams, for instance, by how well the driver can see when meeting another vehicle. Tests of performance of this sort have frequently been carried out for meeting beams, but in almost all of them the lamps used have been new and have been correctly aimed. The conditions of the test have therefore been different from conditions on the road, and the tests may be misleading because they entirely omit the effects of misaim and deterioration, which in practice (in England at least) are of considerable importance. These effects would remain even if, as in the United States, all vehicles were fitted with lamps of essentially the same design. There would still be differences in the effective intensities of the beams on different vehicles, and in consequence, a driver meeting another vehicle would see well enough on some occasions and badly on others. He would also experience very different amounts of discomfort. The performance with which we are concerned is really the aggregate of the performances in the individual encounters, and in judging the suitability of a design all possible encounters should be borne in mind, particularly those in which seeing is poor. It is clear that performance, defined in this way, does not depend solely on the design of the beam itself; indeed, it is meaningless to speak of performance except in relation to a definite standard of aiming and level of deterioration. It follows, therefore, that the choice of beam must depend on the standard of aiming attainable and the degree of deterioration allowed. For example, a beam with a very sharp cutoff might be quite satisfactory if aiming was generally good but give a large proportion of short seeing distances and be intolerably dazzling if aiming was poor. Or again, a beam of low intensity might be satisfactory if a strict standard of maintenance was insisted upon but be unsatisfactory if severe deterioration was tolerated.

The paper shows how this overall performance of a beam may be calculated when the minimum seeing distance during an encounter is taken as a measure of the performance during that encounter. The relations between performance, sharpness of cutoff, and standard of aim are investigated; the effect of deterioration is also considered. Numerical results are obtained for a beam of simple design which approximates to typical modern designs in the region of the beam mainly responsible for glare and for distant seeing on the nearside of the road. These results go some of the way towards putting the design of meeting beams on a rational foundation. For example, if a certain level of performance is specified, then the necessary sharpness of cutoff and standard of aiming can be determined.

Factors which have had to be ignored in the present paper are the pitching motion of the vehicle, due mainly to the irregularity of the road surface, and the intermittent dazzle to which it can give rise. The effect of this will be more marked on beams having a sharp cutoff.

SEEING UNDER CONDITIONS OF GLARE

The glare of approaching headlights reduces a driver's ability to see. But, by revealing as dark silhouettes any pedestrians or vehicles which may be on the road between him and the approaching vehicle, these lights may, at times, actually assist him to see. A driver may see a pedestrian in silhouette long before he is able to see him directly. This silhouette seeing is sometimes of great assistance when direct seeing is poor. But it has been argued that less importance should be attached to it than to direct seeing, because it is not always effective and cannot, in any case, reveal a pedestrian who does not step on to the road until the approaching vehicle has passed him. In this paper the possibility of silhouette seeing is ignored, and discussion is confined to the performance of lamps in direct seeing.

The performance of a meeting beam in a single encounter is found by fitting two cars with identical beams and running them against one another on a straight track on which certain objects of a standard form have been placed. By means of distance-recording mechanisms in the vehicles, the drivers are able to record the distances at which they first see the object; after a number of runs with objects in different positions, a curve can be drawn which shows the seeing distance as a function of the separation between the vehicles, as in Figure 1, which is based on results given by Roper (1). The seeing distance diminishes as the vehicles approach each other, reaches a minimum before they meet, and then rises again more rapidly as the vehicles pass and the eyes recover from the effect of the glare. It is common to attach considerable importance to the minimum distance and to attempt to increase it by improvements in design so that it shall exceed the stopping distance by a comfortable margin. We shall therefore adopt it as a measure of the performance of the beam during the encounter and enquire how this minimum seeing distance is affected by lamp design and by misaim and deterioration.

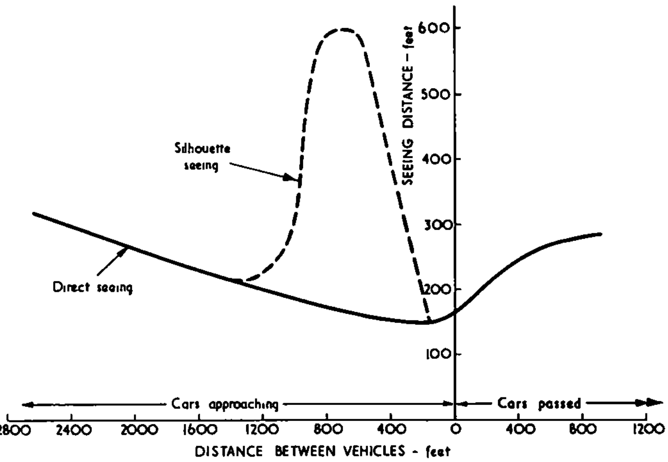

Figure 1. Seeing distance as function of distance between vehicles (after Roper).

BASIC DATA AND ASSUMPTIONS

The minimum seeing distance is obtained for an object which is almost level with the approaching vehicle at the moment of perception. Since, near a minimum, values do not change very rapidly, the seeing distance for an object just beyond the glare source is approximately equal to the minimum. Roper (2) has investigated seeing distance for this position. In his tests the glare vehicle was stationary, but such tests appear to give much the same result, as far as direct seeing is concerned, as those in which both vehicles are moving. Beams of uniform intensity were used so that the intensity directed at the object or at the driver's eyes did not change during the test run. This work has been extended at the Road Research Laboratory to those lower values of illumination and glare which are of particular importance in the design of meeting beams (3). The experimental results for a single observer have been plotted as smoothed curves in Figure 2. The question arises whether the same seeing distances would have been obtained with more-normal beams in which the intensities of illumination and glare were not uniform and would, therefore, have changed during the approach of the vehicles. This has been investigated by comparing, for a number of lamps, the seeing distances actually obtained in tests and those obtained by calculation from the beam distributions (4). It was found that the agreement was reasonably good, particularly as regards the relative performances of the different lamps. It will therefore be assumed that the results in Figure 2 apply to any distribution and that minimum seeing distances can be calculated from these curves and the beam distributions. It should be remembered, however, that these results are not completely general. They apply to conditions similar to those of the tests in which they were obtained. Briefly, the seeing distance is that for an object about 1.5 ft. high, with a reflection factor of 7 percent, seen on the nearside of a 20-ft. road. This standard object is a good deal lighter than the darkest clothing, which has a reflection factor of 2 percent or less, but is of smaller size than the average pedestrian. The broken curves in Figure 2 show that, provided the ratio of illumination intensity to glare intensity is kept fixed, an increase in absolute magnitude produces only a small change in seeing distance. In Figure 3 the same results have been plotted in a different way to show the ratio of illumination intensity to glare intensity required to achieve a minimum seeing distance of any desired value. These curves are more useful for our purpose than Figure 2.

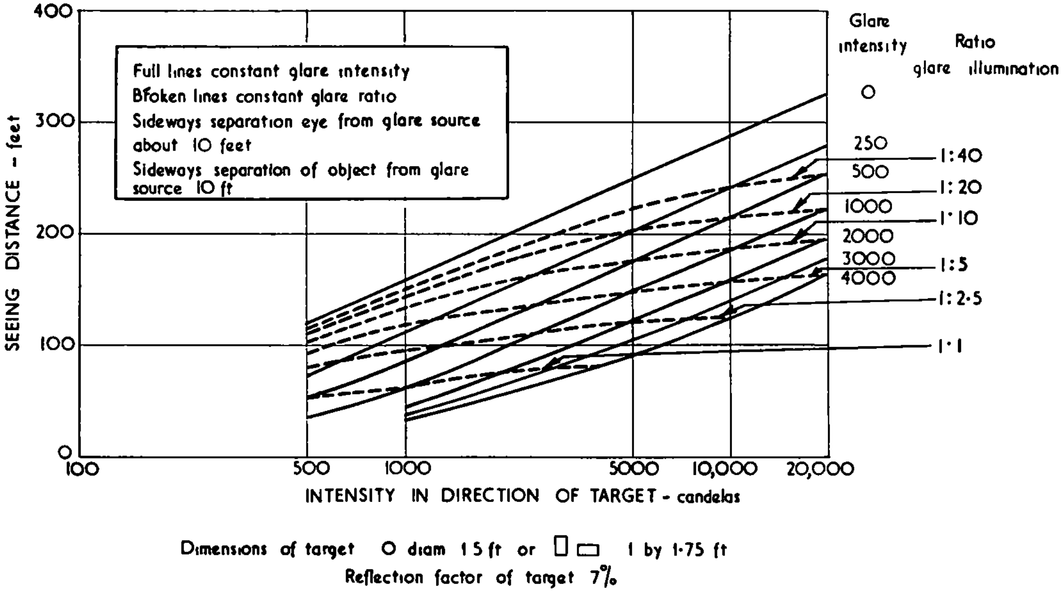

Figure 2. Seeing distance as function of glare and illumination intensities.

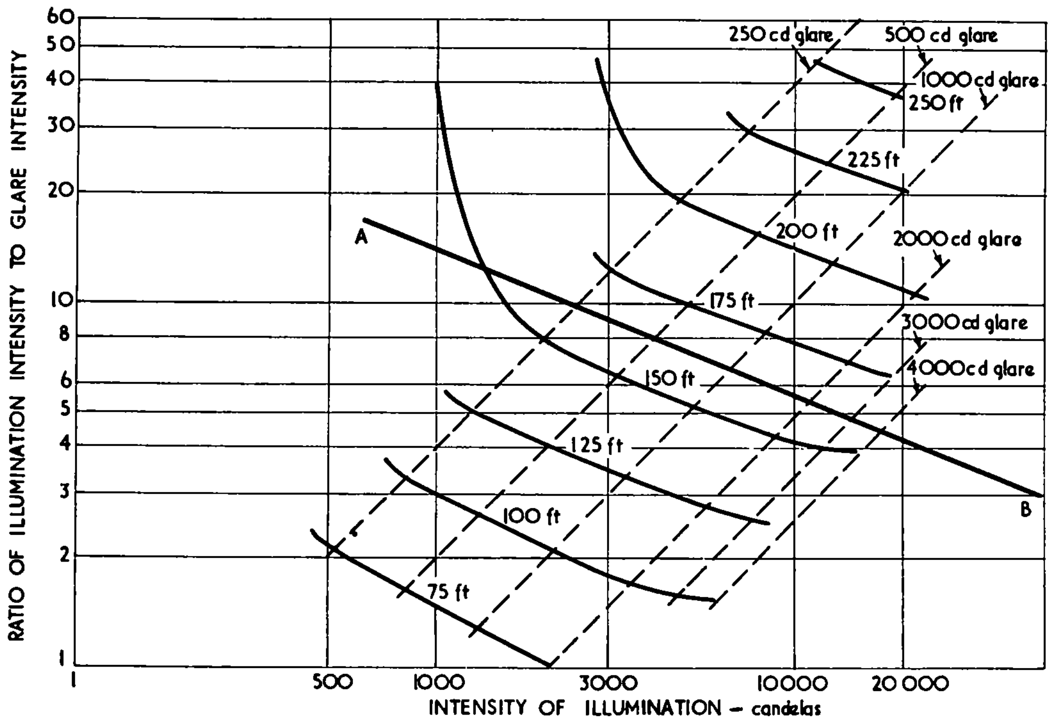

Figure 3. Seeing distance as function of illumination intensity and ratio of illumination to glare.

TYPICAL FEATURES OF BEAM DISTRIBUTION

Figures 4, 5, and 6 show the beam distributions from one lamp (5) of a British, an American, and a European meeting beam. Figure 4 also shows the

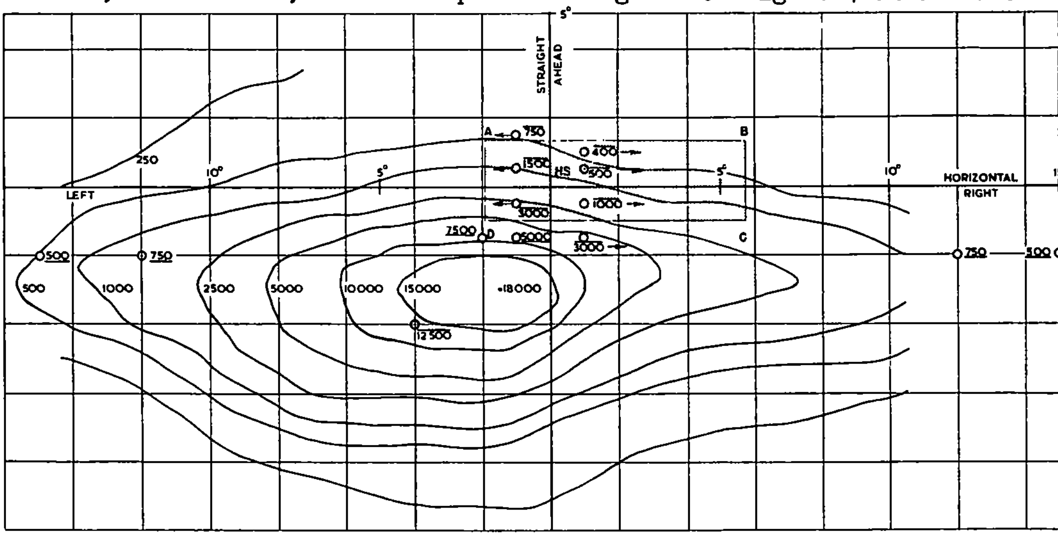

Figure 4. Beam distribution from one lamp of Lucas FF 700 system. Also SAE recommended practice for sealed-beam lamp. (Reversed from left to right to suit British rule of road.)

American intensity limits according to the specification of the Society of Automotive Engineers, reversed from left to right to fit the British rule of the road. The origin HS represents the horizontal direction straight ahead through the lamp; other directions are given in terms of their angular displacement to offside and nearside or up and down. Objects on a straight road 150 ft. or more ahead of the vehicle are illuminated by intensities which lie within the region ABCD marked on the diagram; the intensities causing dazzle are also found within this region. In this part

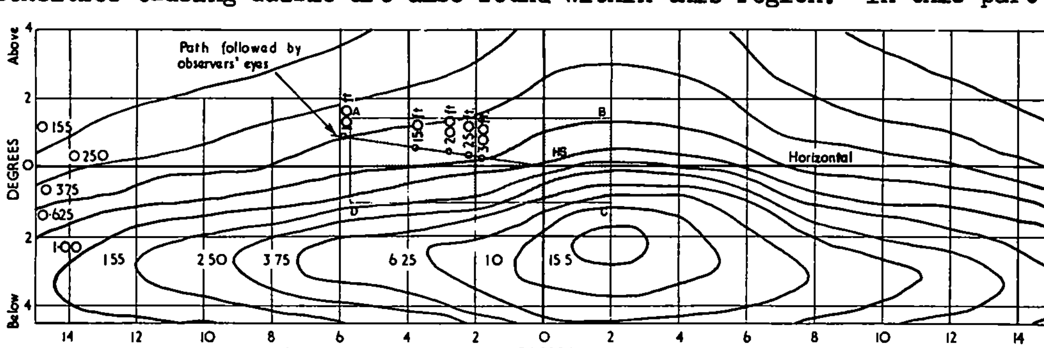

Figure 5. Beam distribution from one lamp of the General Electric Meeting system (see Reference 5).

of the beam the intensity increases in a downward direction. In the British or American lamp it increases towards the nearside also. In the

European lamp, which (unlike British or American lamps) dips vertically downwards without deflecting to the nearside, the beam has a much smaller sideways rate of change. The beam distribution in the region ABCD might be defined by stating the intensity I_o at HS and the rate at which the intensity increases downwards and to the nearside. Unfortunately the rate of change is not constant, so for most existing beams a description of this sort would be somewhat complicated. To simplify the calculations, which

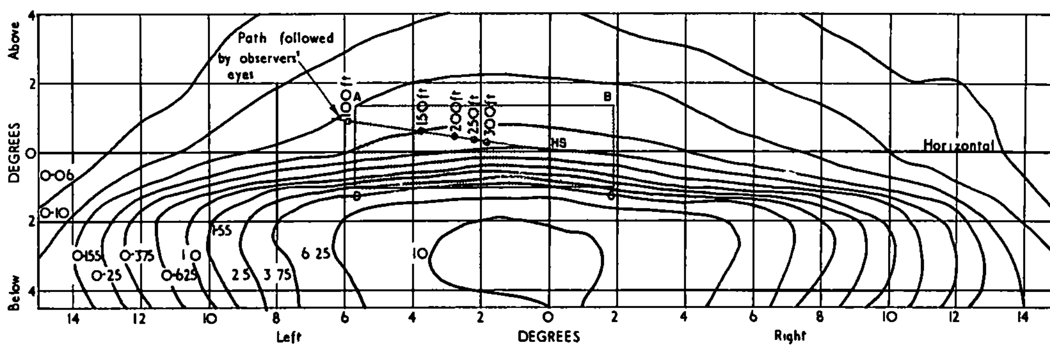

Figure 6. Beam distribution from one lamp of the Cibie meeting system (see Reference 5).

are described later, it will be assumed that the intensity is increased in a constant ratio for each degree downward or to the nearside. With this assumption the isocandela lines of the beam distribution become parallel, straight lines as in Figure 7. These can be fitted fairly closely to many existing patterns in the region which we are considering, although they diverge elsewhere. The factors by which the intensity is increased in a displacement of 1 deg. are denoted by n_1 for sideways and n_2 for downward displacements. The quantities n_1 and n_2 will be called the cutoff factors for side and top cutoff respectively.

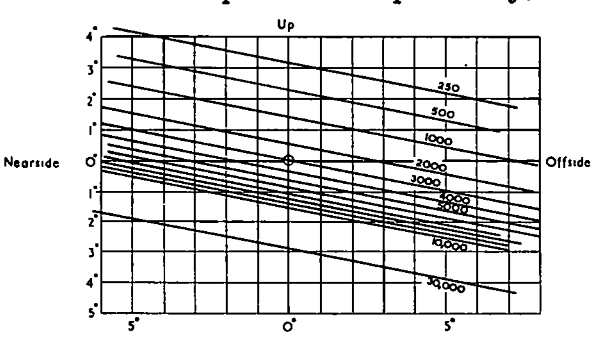

Figure 7. Idealized beam pattern used in calculations (actual example shown here has $n_2 = 2.2$ $n_1 = 1.17$ $I_o = 3000$cd).

Cutoff factors, as already mentioned, are not constant in the important region of typical British, European, or American meeting beams. Table 1 shows typical values of n_2, and it is evident that the European lamp has much higher values of n_2, i.e., much sharper top cutoff than the others. Even in the European lamp the highest values of n_2 are not at the horizontal but a degree or so below. European lamps also differ from the others in having a lower intensity at the horizontal.

TABLE 1

VALUES OF THE TOP CUTOFF FACTOR n_2 AVERAGED OVER RANGES OF 0.5 DEG. IN A VERTICAL PLANE STRAIGHT AHEAD OF THE LAMP

	Below Horizontal		Above Horizontal	
	1.0° to 0.5°	0.5° to 0°	0° to 0.5°	0.5° to 1.0°
British	2.5	2.4	2.2	2.7
American	3.1	4.1	2.3	1.6
European	11.9	6.1	2.2	1.5

AIM OF LAMPS

Errors may be present in both the horizontal and the vertical aim of the beam. It has been found in England that these errors follow fairly closely the normal law of errors and that their magnitude can therefore be defined by means of the standard deviation σ . The standard deviations for horizontal and vertical aim will be denoted by σ_1 and σ_2 respectively. A survey of several-hundred vehicles in Great Britain showed recently (6) that σ_1 and σ_2 were of the order of 2 deg. for the older types of lamp and about 1 deg. for newer vehicles with flush-fitting lamps. Therefore, even on the new vehicles some 25 percent of lamps are aimed more than o.7 deg. too high and another 25 percent 0.7 deg.too low; 5 percent are more than 1.6 deg. too high and another 5 percent 1.6 deg. too low. Vertical misaim is normally more important than horizontal misaim in its effect on driver vision, because top cutoff is sharper than side cutoff. A form of misaim which is distinct from that due to carelessness or neglect is the change of tilt produced by changes of load of the vehicle. This is particularly important for trucks, which may tilt upwards by as much as 3 deg. when being loaded.

BRIEF OUTLINE OF THE CALCULATIONS

Consider a pair of vehicles separated by a distance d on a road like that used in the tests from which Figure 2 and 3 were derived. If the lamps are aimed so that one driver has just reached the point where his seeing distance is a minimum, then the intensity of illumination of the object must be related to the glare intensity in the manner shown in Figure 3 for a seeing distance d. The probability that the intensities would have any of these suitable values can be calculated from the geometry of the layout, the beam pattern, and the probabilities of the necessary amounts of misaim. Thus it is possible to calculate for any beam pattern the probability that the minimum seeing distance for one of the drivers in a chance encounter should have the value d. But it would be a tedious calculation for the ordinary beam pattern, and it may be simplified by adopting the sort of pattern shown in Figure 7. When aiming is poor the intensities with which we are concerned may be derived from almost any part of the beam, but the better the aiming the more they will be restricted. Since the main purpose of the paper is to examine how far conditions may be improved by improvements in the standard of aim, we may, without serious error, assume that the whole of the beam pattern possesses the characteristics found in the restricted regions ABCD in Figures 4, 5 and 6, i.e., that it has the simplified character of Figure 7.

It would be possible, in the calculations, to allow for the fact that the beams encountered suffer from deterioration to varying degrees, but as this would complicate the working, the only cases which have been evaluated are: (1) deteriorated lamps meeting deteriorated lamps, all of which have deteriorated to the same degree, and (2) deteriorated lamps meeting lamps which have not deteriorated.

To carry out the calculations a given design of beam and a given standard of aiming are assumed, (i.e., values of I_0, n_1, n_2, σ_1, and σ_2) and the data in Figure 3. The fact that the curves of Figure 3 turn upwards rapidly at the low intensity end is ignored; the curves are assumed parallel to AB, and in consequence, low intensities of illumination are assumed to be more effective than they really are. It is then possible to calculate quite easily how often a minimum seeing distance falls short of any particular value d, or how often the glare intensity or the ratio of illumination to glare exceeds any chosen value.

In the calculations on which Figures 8 to 12 are based, it is assumed that, except for deteriorated lamps, the intensity straight ahead in the horizontal is 3,000 cd. This is a typical value for the beam from a new British double-dipper system and is higher than American and much higher than European practice. Where side cutoff is not zero, it is assumed that the isocandela lines are inclined at a slope of 1 in 5, as in the British lamp. It is assumed that the lamps are mounted at a height of 2.5 ft. and that at least 1 ft. of the target must be illuminated to the required level for it to become visible.

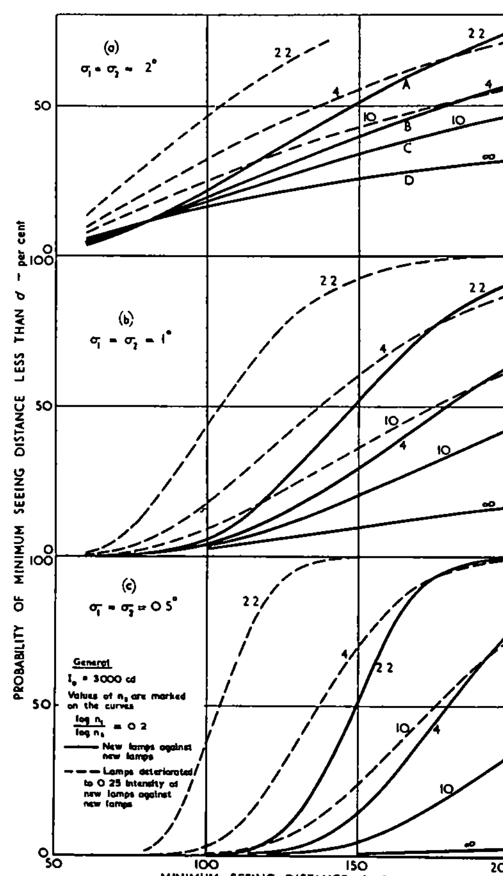

Figure 8. Probability of minimum seeing distance as affected by misaim and deterioration.

,RESULTS OF CALCULATIONS

The results of the calculations are shown in Figures 8 to 12. A word of warning should be given as to the exact meaning of the probabilities shown in these figures. In any encounter there are two drivers and, therefore, two minimum seeing distances, whose values are generally different. The probabilities for minimum seeing distances given in Figures 8, 9, and 10 are calculated on the basis of the number of seeing distances, not on the number of encounters. For example, curve A of Figure 8(a) shows that the probability of distances less than 100 ft. is 22 percent. In 100 encounters

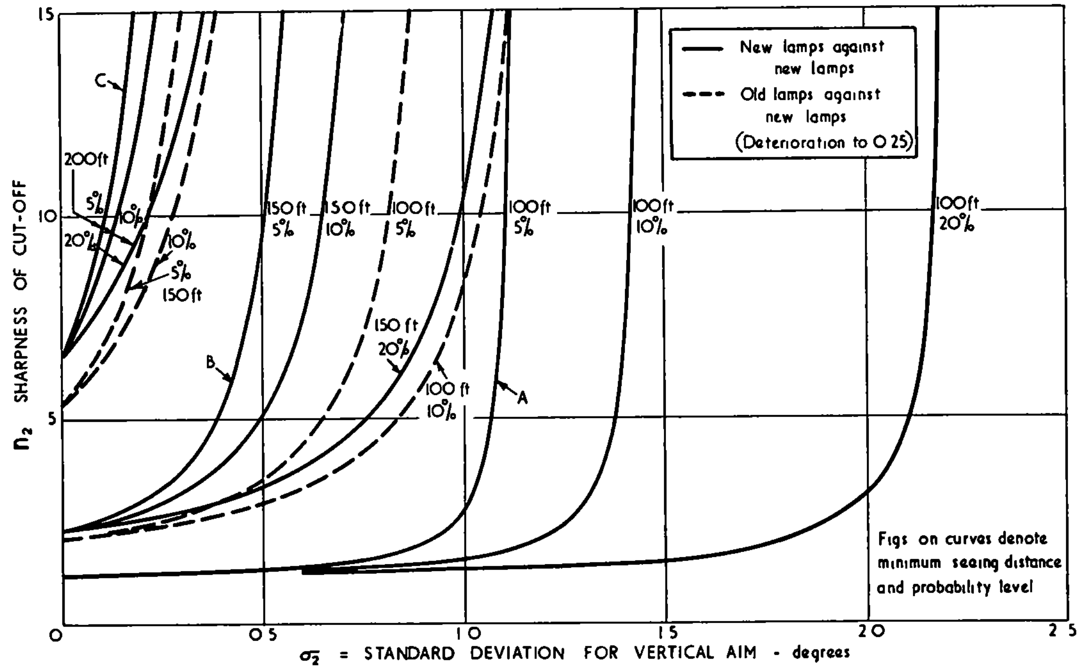

Figure 9. Relation between cutoff and misaim for given probability of given minimum seeing distance.

there are 200 seeing distances and therefore 44 of these may be expected to be less than 100 ft. A large seeing distance for one driver tends to be associated with a small one for his opponent, and these 44 short distances represent just under 44 different encounters; so at least one driver has a minimum seeing distance of less than 100 ft. in about 40 encounters out of 100. Thus, for encounters between similar vehicles, the probability based on the number of encounters is almost double the probability based on the number of seeing distances. When the encounters are between unlike vehicles, as in the broken curves in Figure 8 between vehicles with deteriorated lamps and vehicles with new lamps, the probabilities refer to the seeing distances for one type of vehicle, and the probability is the same whether based on the number of seeing distances or the number of encounters. Similar remarks apply to the probability for glare intensities in Figures 11 and 12.

The Effect of Misaim on Seeing Distance

The full lines in Figure 8 show the probabilities for different values of the cutoff factors and different standards of aiming. Each curve crosses the line denoting 50-percent probability at a distance which is the design distance for that lamp, i.e., if all lamps were of the same design and correctly aimed the minimum seeing distance would be the same for all and would have this value.

In Figure 8(a), Curve A gives results for a lamp approximating closely to the British lamp shown in Figure 4 and for the standard of aim which exists on older cars in Britain today ($\sigma_1 = \sigma_2$ = 2 deg.). Although the

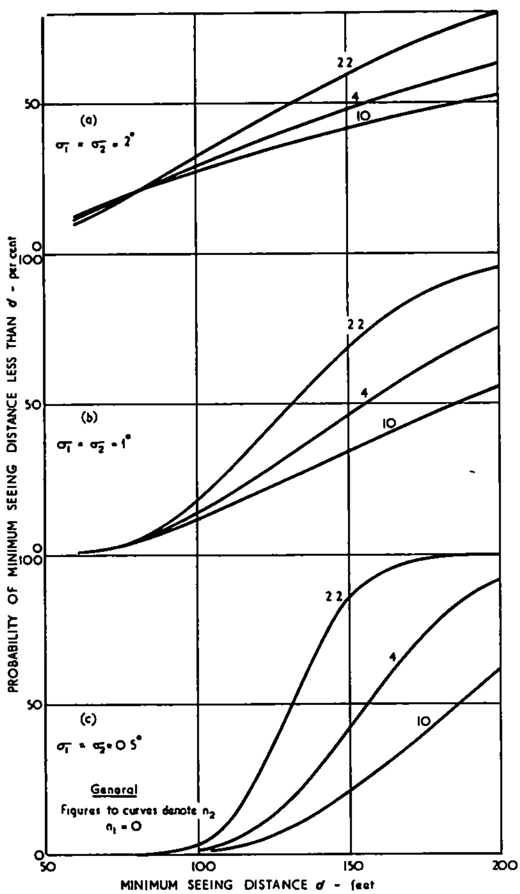

Figure 10. Probability of minimum seeing distance for lamps without side cutoff.

design distance works out at about 150 ft., 22 percent of distances (about 40 percent of encounters) are less than 100 ft.

Curves B, C, and D show the effect of sharpening the cutoff while retaining the same horizontal forward intensity. The design performance is improved, but the probability of getting seeing distances less than 100 ft. is only slightly affected, falling from 22 percent to 18 percent as n_2 is increased from 2.2 (British lamp) to 10 (maximum value for European lamps). The misaim is so large that it swamps the effect of the sharper cutoff at the low-performance end of the curves. At the high-performance end there are, however, far more cases in which the seeing distance is much greater, for example, than 150 or 200 ft.; so there is an improvement, though not where it is presumably most important.

Figures 8 (b) and 8(c) show the results obtained when the misaim is reduced to one half and then to one quarter of that assumed in Figure 8 (a). Design performance is not affected, i.e., the curves still cross the 50-percent probability line at the same values of d, but the probability of distances less than the design value is reduced, and in this example, for instance, the probability of distances less than 100 ft. is greatly reduced. If the standard deviation of aim could be reduced, as in Figure 8(c), to 0.5 deg., seeing distances less than 120 ft. would not occur in more than 5 percent of cases, i.e., in fewer than 10 percent of encounters with the present British lamp. A further improvement would be possible if there were some sharpening of the cutoff.

Another way of setting out the results, one which brings out more clearly the connection between design and standards of aiming, is shown in Figure 9. This shows what values of n_2 and σ_2 are required in order that the probability of distances of 100, 150, or 200 ft. should be kept at some low figure. For example, if seeing distances less than 100 ft. are to form 5 percent or less of the total, then n_2 and σ_2 must be given by points on or to the left of Curve A. If σ_2 is 2 deg., this is clearly impossible. If σ_2 just exceeds 1.1 deg. it becomes possible, but a sharp cutoff (n_2 greater than 8) is required. If σ_2 is less than 1 deg., it is possible to obtain the low probability with values of n_2 as low as that for the British lamp, or even lower.

Curve B for 150 ft. is similar but more demanding, both as regards aim and sharpness of cutoff. Curve C for 200 ft. calls for a still sharper cutoff and a standard of aiming so high that in order to attain it lamps on trucks would certainly have to be adjusted for changes of load, and it might even be necessary to readjust the aim on cars according to the number of passengers in the back seat. The addition of one passenger tilts the average British car about 0.2 deg.

Effect of Deterioration

It has been assumed in calculating the results given by the full lines in Figures 8 and 9 that the only differences between the beams on different vehicles were due to misaim. In practice there would be differences due to deterioration and to the effect of manufacturing tolerances which allow quite considerable variations between beam and beam. Drivers whose lamps have deteriorated will experience short seeing distances more frequently than the drivers we have just been considering, whose lights, though misaimed, are at least giving a normal output. Calculations have been made for lamps whose output in any direction is only one quarter of the normal. It is assumed that these lamps suffer from misaim as before. The probability of minimum seeing distances for drivers using these lamps but meeting new lamps is shown by broken lines in Figures 8 and 9. It is clear that for a seeing distance of 100 ft. the demands are fairly severe and for 150 ft. well-nigh impossible, somewhat similar, in fact, to the requirements for a seeing distance of 200 ft. with new lamps.

A more-elaborate study of the effect of mixing beams with various levels of deterioration is clearly required to give a true picture of the importance of deterioration. The results just quoted show, however, that a general deterioration to one quarter of the initial intensity will very seriously handicap the user when meeting beams from undeteriorated lamps. It is interesting in this connection that the recommended SAE standard is one half of the initial intensity.

Effect of Side Cutoff

Figure 10 gives the probabilities for beams which differ from those of Figure 8 (full lines) only in having no side cutoff. The curves show that the side cutoff adopted in the idealized beam (similar to that of the British lamp in Figure 4) increases the seeing distance by about 20 ft. For sharper side cutoff (isocandela lines sloping down more sharply) the increase would have been larger. The improvement thus produced in the visibility of objects on the nearside of the road may, however, be accompanied by a deterioration for objects more to the offside. If side cutoff is used it should not extend much below the horizontal or the visibility on the offside of the road will be seriously reduced.

Intensities of Glare

The discomfort caused by a headlight does not depend simply on the intensity of the beam, but intensity is probably the most-important factor. When the design of the meeting beam is governed by regulation, it is usual to have an upper limit to the intensity which can be directed into the eyes of approaching drivers. It is of interest, therefore, to find the effects of misaim and sharpness of cutoff on the intensities actually encountered.

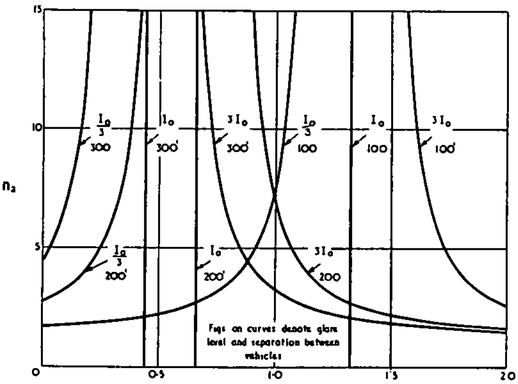

Figure 11. Relation between cutoff and misaim for 5-percent probability of glare exceeding $\frac{I_o}{3}$, I_o and $3\ I_o$.

Figures 11 and 12 give some results for the simplified beam of Figure 7. It is assumed, as before, that the horizontal intensity is maintained at the fixed value I_o, while the sharpness of the cutoff is varied. Figure 11 is similar to Figure 9 and shows the relationship between cutoff and aim required to keep the probabilities at the 5-percent level. Curves have to be drawn for each separation of the vehicles and each level of glare. The glare levels chosen for Figure 11 and 12 are horizontal intensity. I_o and one third and three times this intensity, i.e., 1,000, 3,000 and 9,000 cd. according to Figure 7. The glare intensity will not exceed the chosen value in more than 5 percent of cases, provided that the aim and cutoff are represented by a point on or to the left of the appropriate curve. As with the curves for seeing distance, the probabilities are calculated on the number of glare intensities, which is double the number of encounters, and the probability for encounters is not 5 percent but almost 10 percent.

In Figure 11, probabilities for glare intensities exceeding I_o are clearly independent of the cutoff, and for this special case the general relationship between probability and standard of aiming is given in Figure 12. The probability remains constant for this particular value of glare, because it is being assumed that I_o remains constant while the cutoff is changed. The misaim required to bring this intensity to the driver's eyes remains constant and so, therefore, does the probability. Other assumptions might clearly be made; in some countries, the United States for example, the intensities which are limited by legislation or agreement extend below the horizontal. Figures 11 and 12 may be used in investigating such conditions provided I_o is then regarded as dependent on the cutoff factor n_2.

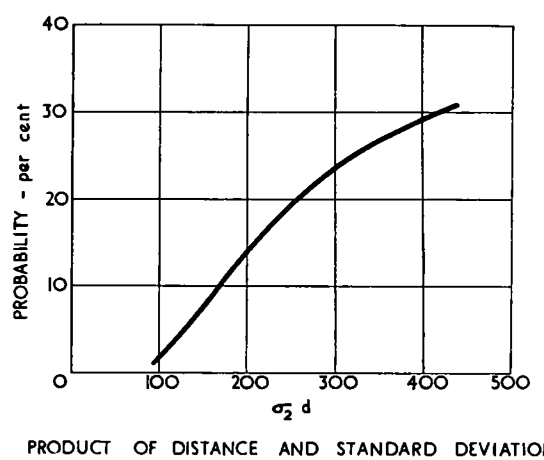

Figure 12. Probability of glare intensities exceeding the forward intensity in the horizontal I_o.

It is an important question whether changes in cutoff necessary to achieve large seeing distances can be made without running into serious trouble from high intensities of glare. An improvement in the standard of aiming makes it less likely that high glare intensities will be encountered; the effect of sharpening the cutoff is more complicated. If the cutoff is made sharper, high intensities become more probable and low intensities less probable; the intensity for which the probability remains unchanged is, as we have already shown, the intensity which remains fixed while the cutoff is varied, i.e., in our calculations the horizontal intensity I_o. A comparison of Figures 9 and 11 shows that to keep down intensities exceeding $I_o/3$ (1,000 cd.) to a probability of 5 percent at a distance of 200 ft. requires standards of aiming and sharpness of cutoff similar to those required to achieve seeing distances of the same order with the same probability level. There is, in fact, a correspondence between the two diagrams which may be expressed as follows: If the cutoff and standard of aiming give probability p for seeing distances less than d, then when the vehicles are separated by a distance d the probability for glare intensities exceeding kI_o is also less than p. The factor k is a function of the separation and is given in the following table. For distances greater than 150 ft. it is less than 0.3.

d ft.	100	150	200	300	400
k	0.7	0.3	0.125	0.02	0.004

It follows from this that if as a result of sharpening the cutoff and improving the aim the performance of beams is improved as to seeing distance it will also be improved as to glare intensities. This suggests that apart from intermittent glare due to the pitching motion of vehicles comfort will look after itself if visibility is dealt with. It is the intermittent glare, therefore, which probably sets an ultimate limit to the sharpness of cutoff that can be used.

CONCLUSIONS

The effectiveness of a meeting beam should be judged not by its performance when correctly aimed and in perfect condition but by the performances which will be given by such beams in actual use when subject to the inevitable effects of misaim and deterioration. A method of evaluating this overall performance is given, based on the minimum seeing distance and the glare intensity.

Judged in this way the performance of any given design depends on the standard of aiming and on the degree of deterioration which is to be tolerated. Curves are given from which the effects of the various factors and the connections between them may be seen.

An attempt to increase the minimum direct-seeing distance at most encounters to much over 150 ft. for the standard test layout makes demands as to accuracy of aiming and sharpness of cutoff which it will be difficult to meet, especially if deterioration to a small fraction of initial intensities is tolerated. The prospects of designing a beam which will effect any considerable improvement are therefore small.

The sharp cutoff, coupled with a high standard of aiming which is required if improved seeing distances are to be attained, is not likely to give rise to high intensities of glare, except for intermittent glare due to the pitching motion of the vehicle, or at places, such as hilltops, where the slope of the road is not constant. If it may be assumed that standards of aiming can be greatly improved, then it is the intermittent dazzle due to the pitching motion which probably sets a limit to the sharpness of cut-off which may be used.

ACKNOWLEDGEMENTS

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GLARE from PASSING BEAMS of AUTOMOBILE HEADLIGHTS

Geoffrey Grime
Road Research Laboratory
Harmondsworth, England

SYNOPSIS

Measurements of glare intensity from the lower (dipped) beams of vehicle headlights were made at sites in Texas, Maryland, New Jersey, and in the District of Columbia in the summer of 1952. The results show that in the two states which had well-established vehicle-inspection procedures (New Jersey and the District of Columbia), glare was slightly less than in Maryland, which had no inspection, and in Texas where inspection had just begun. At all places, a few very-badly adjusted headlamps were met.

Although glare from lower beams was found to be reasonably low, the situation as regards deterioration was less satisfactory. With the help of the Bureau of Public Roads, measurements were made, at two inspection stations in Washington, of the maximum intensities of the country beams of vehicles as presented for inspection. It was found that the light output of many lamps had deteriorated badly; but because the candlepower limit at inspections was so low, few of these deteriorated lamps were rejected. Combining these results with those of the glare survey in Washington, rough calculations were made which indicated that, because of the large deterioration allowed, the distance a Washington driver can see when meeting another motorist at night is, for many such meetings, only a fraction of what it might be if all lamps were maintained as new.

Counts made on rural roads in Texas showed that 20 to 25 percent of drivers met refused to dip (change to lower beam). It is not known whether the same high proportion is met elsewhere, but it appears probable that most of the glare nuisance in the United States is due to this reluctance to use the lower beam.

FOR some time past, research has been going on at the Road Research Laboratory, England, with particular reference to British conditions, to find ways of reducing dazzle (glare) and improving visibility when vehicles meet at night. One of the conclusions is that an important first step might be to encourage or enforce in Britain the use of a standard headlight, such as the sealed beam now in almost universal use in the United States. It is therefore of interest to know how American headlights compare with British, particularly as regards glare. When the author visited the United States in 1952 as a Commonwealth Fund Fellow, the opportunity was taken to obtain American data with which to make the comparison. Measurements of the glare intensity from the lower beams of headlights were made in a number of states, and some information on the maximum intensity in the upper beams was also collected. It is intended later to obtain comparable data in Britain. This report describes the apparatus constructed for the American measurements and the results.

DATA OBTAINED

Measurements of dazzle intensity, that is, of the intensity directed towards the eyes of a driver by the headlights of an oncoming vehicle, were made in Texas, Maryland, New Jersey, and Washington, D. C. New Jersey and the District of Columbia have well-organized state-run vehicle-inspection stations, whereas Maryland has no inspection and Texas has only just started a garage-operated scheme (1952). If vehicle-inspection is effective, less glare is likely to be found in Washington and New Jersey than elsewhere; the measurements were expected to give information on this matter.

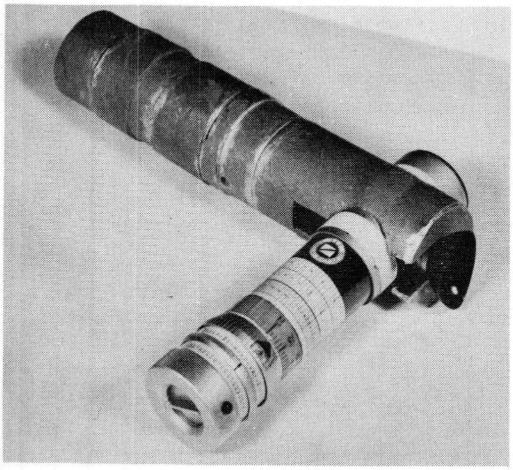

Figure 1. Glare meter.

The measurements of glare intensity were made with an S.E.I. photometer, fitted with the attachment shown in Figure 1. The photometer is an instrument for measuring the luminance (brightness) of a surface by matching it visually with a spot of known brightness. The attachment consists of a lens, A, which is directed towards the headlamp whose intensity is to be measured (see Fig. 2). A diffusing screen, B, placed some distance within the focal length of the lens, receives a defocussed image of the headlamp. The brightness of this image, which at a given distance is proportional to the intensity, is measured with the S.E.I. photometer, and from a calibration curve the intensity may be deduced. The distance of the diffusing screen from Lens A is such that, at 300 ft. (the usual viewing distance), the images of the two headlamps overlap and a single reading of combined intensity can be made. Fuller details of the instrument and of the method of calibration are given in the appendix.

All the observations were made from a stationary car parked about 350 ft. from a traffic light. The distance of the vehicle from the stop line was measured with a "Rolatape", a rubber-tired wheel, 2 ft. in circumference, equipped with a revolution counter, and mounted at the end of a "lazy-tongs" handle, so that it could be wheeled along the road. Particulars of the sites are given in Table 1.

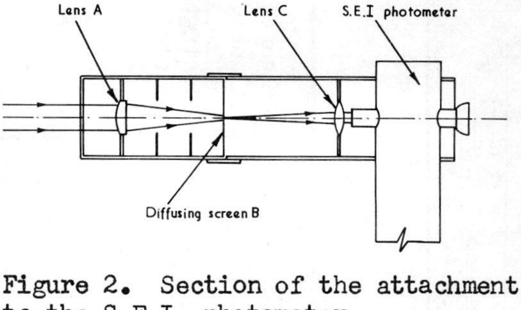

Figure 2. Section of the attachment to the S.E.I. photometer.

"The effect of glare, both as regards disability and discomfort, depends more on the ratio of glare intensity to intensity directed towards the object than on the absolute value of the glare intensity, (1)and it

TABLE 1

Date	Place	Number of Obser-vations	Distance of Observer	Street Width	Viewing Angle*	Remarks
			ft.	ft.	deg.	
13 and 14.5.52	Kilgore, Texas	54	302	40	3	Level road
10.7.52	Kilgore, Texas	39	316	40	4	Level road
3.8.52	Washington, D.C. I Street and 16th	59	348	36	2.8 in one lane	Slope of about 0.8° increasing the de-pression of beams.
4.8.52	I Street at 18th	30	350	36	As at 16th	Level road
8.8.52	K Street at 18th	55	370	45	3.3 in one lane 4.6 in one lane	Slope of about 0.7° decreasing depression of beams.
14.8.52	L Street and 17th	36	330	About 30	1	One-way street: Level: room for one lane of traffic only.
15.8.52	Aberdeen Maryland	20	333	42	3.6 in one lane 5.3 in other lane	Level road
16.8.52	Frederick Maryland	72	352	30	2.8	Level road: One line of cars
17.8.52	Trenton New Jersey	53	310	35	3.8	Level road: One line of cars: slight bend in road.
18.8.52	Trenton New Jersey	53	388	37	4.6	Level road: only one lane visible

*The viewing angle is the angle between the longitudinal axis of the car being observed and a line from the observer to a point midway between the headlamps.

would therefore have been desirable to have measured the intensities directed along the road towards the object. This was not possible; instead, measurements were made of the maximum candlepower of the upper beam, which might be expected to be proportional to the value sought. A large number of values of the maximum candlepower of the upper beam were obtained for the author by the Traffic Research Department of the Bureau of Public Roads, who recorded the results of routine inspection tests at the two vehicle-inspection stations in Washington, D. C. Thanks are due to the Bureau of Public Roads for permission to include the results in this paper. The maximum candlepowers of the upper beams were recorded for 1,200 cars and trucks by means of Kent-Moore "Robot" headlight-testing machines. When in use, the Robot is placed in front of the headlamps and a large lens inside the instrument gathers the light and focusses it on a photocell. A meter calibrated to read directly in candlepower is connected to the cell. At Washington testing stations, the meters are calibrated frequently by means of a standard sealed-beam headlamp. An undesirable feature of the instrument is that the candlepower scale is nonlinear and difficult to read accurately at the upper end.

RESULTS

The results of the surveys are shown in Figure 3, which comprises five diagrams; the first three relate to conditions in Washington, D. C., and New Jersey, where well-conducted vehicle-inspection programs are in operation; the last two refer to Maryland, which has no inspection, and to Texas, where inspection by appointed garages had been in progress for a few months only when the measurements were made.

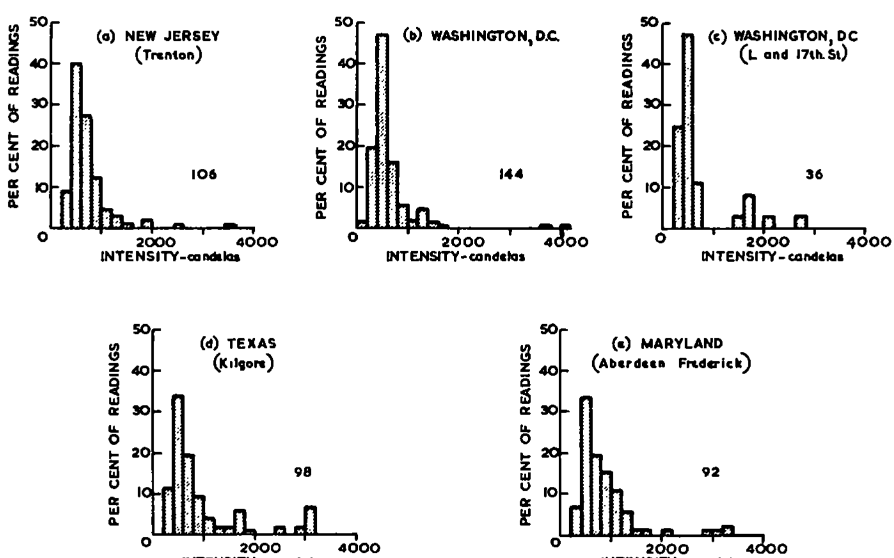

Figure 3. Glare intensities in the United States: (a), (b), and (c), states having inspection; (d) and (e), no inspection (Maryland) or inspection just started (Texas).

All the results show a low level of glare, the most frequently measured intensities at all sites lying between 400 and 600 candelas.* Even more important, perhaps, than the low level of glare is the shape of the frequency diagram, with 60 or 70 percent of the readings concentrated between 400 and 800 candelas. This suggests good aiming.

A visual comparison of the diagrams suggests that there was less glare in those states which had vehicle inspection than in those which had no inspection, and this indication is confirmed by calculations which show that significantly more vehicles with dazzle intensities over 800 candelas were observed in Maryland and Texas than in New Jersey and Washington, D. C. The differences might have been more easily detectable had it been possible to measure all glare intensities from the same position in relation to the axis of the vehicle; at many sites, however, it was uncertain which of two lanes the vehicle under observation was in, and some scatter must have been introduced into the results because of this fact. At the L Street site, a one-way street in Washington, D. C., the observations were all made on one lane of traffic from a position much nearer to that lane than was usual in other tests; the results are therefore given separately in Figure 3(c).

Although the general level of dazzle in the United States was found to be low, there was an appreciable proportion of badly adjusted headlights, even in states having inspection; in Washington for example, 10 percent were over 1,000 candelas; in Maryland, about 25 percent were over 1,000 candelas.

Another feature of the results which should give rise to concern is the extent of the deterioration of the intensities of the upper beams, which are an indication of the condition of the lamps as a whole. Figures for the maximum intensities of the upper beams, as measured in Washington inspection stations by the procedure already described, are given in Figure 4. It will be seen that there was a considerable deterioration from the design candlepowers of the upper beams (for a pair 64,000 at 6.4 volts, or probably about 52,000 for the test conditions). Since these figures were obtained at inspection stations and since the rejection limit in Washington is low (5,000 candlepower for each lamp) the state of vehicle headlights in use on the roads may well be worse than these figures suggest. Assuming them to be representative, however, the effect of this deterioration on the seeing distances of Washington motorists has been roughly calculated, making use of the data in Figures 3(b) and 4, in the following way. The glare intensities were assumed to be the same at all distances and to be given by Figure 3(b); this overestimates glare at the shorter

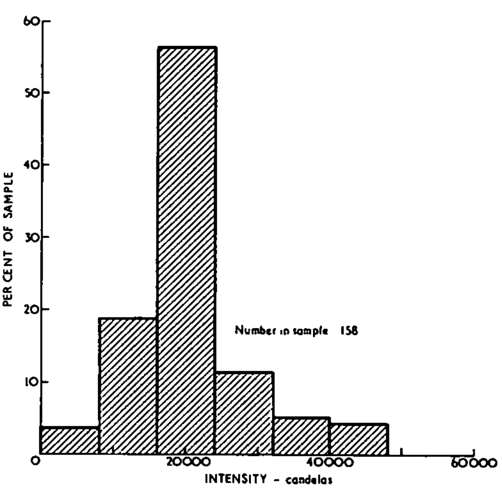

Figure 4. Maximum combined intensities of two upper beams, measured at Washington, D. C., inspection stations.

*The new international candle, virtually the same as the American standard candle.--Ed.

distance. The upper-beam maximum candlepowers were assumed to be as in Figure 4. Misaim of the beam was neglected and the intensity directed along the road towards the object to be detected was derived from Figure 4 by assuming that it was a constant fraction (1/10) of the maximum intensity in the upper beam. This fraction was estimated from the isocandels diagrams for new lamps and therefore the procedure implied that deterioration had not affected the beam pattern, a reasonable assumption for sealed headlights, and that the relative intensities of the upper and lower beams were as given by the design values for new lamps. This last assumption may be inaccurate. Making these assumptions, rough calculations of the resulting distribution of seeing distances were made by a method recently developed at the Road Research Laboratory, (2) based on practical measurements of seeing distances. The results are set out in Figure 5. The meaning of this figure may be stated in the following way. If a large number of Washington vehicles, picked at random, meet at night an equal number also randomly picked, and all vehicles use their lower beams, approximately 3 percent of the drivers are likely to have seeing distances in the range 0 to 50 ft., 22 percent 50 to 100 ft., 64.5 percent 100 to 150 ft., 10 percent 150 to 200 ft., and 0.5 percent 200 to 250 ft. To compare with these figures, it has been calculated that if all lamps had the candlepower they were designed to produce, and were correctly aimed, all drivers would have a seeing distance of 152 ft. Therefore, because of deterioration, one quarter of the seeing distances are less than two thirds of what they might be, if everything were perfect, and 10 percent are slightly greater. Considerable improvement might be expected to result from a tighter control on deterioration, and it also appears likely that the causes of deterioration would repay investigation.

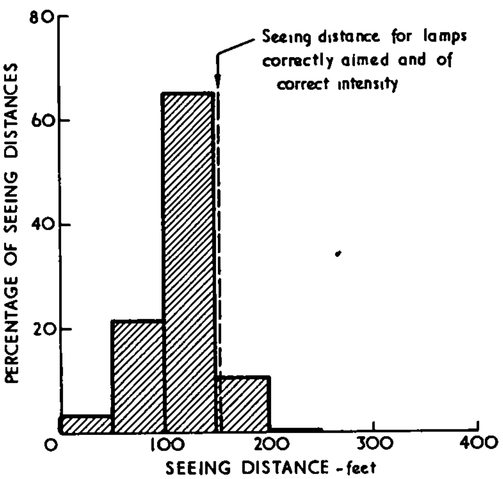

Figure 5. Calculated seeing distances for Washington, D. C.

The investigations described in this note have shown that glare from the lower beams of American vehicles is slight, but in the course of the work it was noticed that many American drivers refused to "dip" their headlights (change to lower beam) or left it far too late. Two counts, made on rural roads in Texas, showed that 20 to 25 percent of all drivers met kept their upper beams on, or did not change until they were very near. Unfortunately, no observations were made in any other states, and it is not known whether the same high proportion is met elsewhere. Even if the proportion in other states is lower, it still seems likely that most of the dazzle nuisance in the United States of America is due to this reluctance to use the lower beam. This is in contrast to the situation in Great Britain where glare is mainly due to misaim and deterioration, and only to a minor extent to refusal to change to lower beam (3).

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2. V. J. Jehu, "A Method of Comparing the Performance of Vehicle Meeting Beams." Road Research Laboratory Note No. RN/1597/VJJ, July 1951. (Unpublished.)
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APPENDIX

The Glare Meter

The glare meter used for the measurements described in this paper was designed to fulfil the need for a small portable instrument requiring no elaborate apparatus or electrical supplies, and capable of being brought into use quickly whenever a suitable opportunity occurred. The basis of the meter is the S.E.I. visual photometer with which the luminance (brightness) of a surface can be measured. The instrument consists of a small telescope of unit magnification, which is pointed at the object. In the center of the field of view is a comparison spot, whose brightness can be matched to that of the object by adjusting a calibrated rheostat fitted with a logarithmic scale. At comparatively short distances the intensities of a headlamp or pair of headlamps may readily be determined with an instrument of this type by using it to measure the luminance of a white surface of known luminance factor placed at a known distance from the lamp or lamps. If the luminance factor of the surface is β , and the measured luminance at a distance d is α foot lamberts, then the intensity in candelas is

$$c = \frac{\alpha}{\beta} d^2$$

For the purpose of the investigation, however, this simple arrangement had to be modified to (1) provide increased sensitivity in order to be able to measure small intensities and to work at large distances, and (2) screen off unwanted light from street lamps and other headlights. The way this was done is shown in Figures 1 and 2.

Lens A in Figure 1 is directed towards the lamp to be measured and produces a rectangular defocussed image on the diffusing screen, B. The brightness of this image, as seen through the diffusing screen, is then measured with the S.E.I. photometer, through auxiliary Lens C. Lens A has a focal length of 2.75 in. and is fitted with a rectangular stop measuring 0.75 in. by 0.375 in. It is placed at a distance of 2.45 in. from the diffusing screen, on which it produces a rectangular image about 0.08 in. long; the luminance of this image is found to be about 40 times greater than that of a perfectly diffusing plate illuminated directly by the lamp being measured.

The optical components are mounted in a stout cardboard tube, which can be firmly attached to the S.E.I. photometer in the manner shown in Figure 1. The tube is divided into two parts at the paper screen, and is provided with suitable internal baffles to intercept stray light.

Before use, the cardboard tube is adjusted so that the comparison spot of the photometer is centered on the diffusing screen which is marked to enable this to be done. This ensures that the same part of the screen is always used.

The glare meter was generally used at a distance of about 350 ft., and both lamps of a vehicle were measured at once. This was readily done, since at distances greater than 250 ft., the images of the two headlights overlap enough for a single measurement of combined luminance to be made. Reference to a calibration curve for the appropriate distance then gives the intensity.

The glare meter was calibrated in the United States with a car headlamp, operated on its upper beam, as light source. A white plate of known luminance factor was set up at 300 ft. from the lamp and five measurements of its luminance were made. Five measurements were then made with the dazzle meter from exactly the same position. This procedure was repeated from different positions with respect to the axis of the beam. Intensities of several thousand candelas had to be used in this method of calibration, and it had the disadvantage that extrapolation of the results had to be made.

In a second method, by which another calibration was later made at the Road Research Laboratory, a headlamp, whose light output could be varied over the range of intensity encountered in the glare measurements, was viewed from a distance of 300 ft., and the readings were compared with those of a photoelectric light meter of known calibration. The resulting calibration curves were used for the analysis of the glare results. They refer to two headlamps and therefore include a correction to take account of the imperfect diffusing properties of the paper screen, which result in the combined reading being 10 percent less than the sum of the two readings taken separately.

The standard error of a single reading of the meter is estimated to be 10 percent.

The Highway Research Board is organized under the auspices of the Division of Engineering and Industrial Research of the National Research Council to provide a clearinghouse for highway research activities and information. The National Research Council is the operating agency of the National Academy of Sciences, a private organization of eminent American scientists chartered in 1863 (under a special act of Congress) to "investigate, examine, experiment, and report on any subject of science or art."