Cooperative Road Tests of Night Visibility Through Heat-Absorbing Glass

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Seventeen thousand individual observations of "seeing distance" have been made in road tests carried out cooperatively by the Automobile Manufacturers Association, General Electric, and General Motors. The purpose of the tests was to determine, under actual night driving conditions, the effect of heat-absorbing glass on nighttime visibility. Observations were made of the distance at which obstacles could first be seen from cars traveling 40 mph. against approaching headlights. The tests were similar to those previously described by Roper[1] except that the seeing task of the observer was made much more difficult in some of these more recent tests by using blacker obstacles, by using a black-top road instead of concrete, and by reducing illumination from the headlights. The average difference in nighttime seeing distance through heat-absorbing glass compared to ordinary windshield glass in these experiments was around 3 percent. This agrees with the earlier observations described by Roper taken under less difficult seeing conditions.

● THE principal advantage of "tinted" or heat-absorbing glass is that it absorbs more than half the sun's radiant energy in the infrared. Thus it increases the comfort of the occupants of the automobile by protecting them from the hot rays of the sun when it shines through the windshield and windows. It also reduces daytime glare and is advantageous even in winter when the ground is white with snow.

Automotive use of heat absorbing glass is relatively new. It was first introduced on one make of car in 1950 and it was not until 1952 that it became available on all makes. It is optional equipment for which the customer pays extra — from $25 to $45. Nevertheless, the total number of cars ordered with heat absorbing glass now exceeds five million according to a recent check with automobile manufacturers. This demonstrates the popularity and importance of this new glazing material in the automotive field.

In achieving high absorption in the infrared region, the glass manufacturers have found it necessary also to reduce luminous transmittance to about 73 percent, as compared to about 87 percent with conventional safety-glass windshields. Although this 73 percent is well within the A. S. A. standards for windshield material, it nevertheless represents a reduction in luminous transmittance as compared with conventional windshields. Thus it is apparent that an object viewed through heat-absorbing glass will appear somewhat less bright than when viewed through a conventional windshield. It might at first seem that this reduction in brightness would result in an equal loss in our ability to see the object. A moment's consideration, however, shows that this is not necessarily the case. The eye is very adaptable to changes within the daytime range of brightness and thus it sees objects equally as well through the heat-absorbing glass as through conventional glass during the daytime. At night when light levels are reduced, the eye is less effective in compensating for loss of brightness. Thus, the question occasionally has been raised as to whether the use of heat-absorbing glass reduces nighttime visibility.

Extensive tests have already been run to determine whether there is an appreciable loss in the distance at which objects can be detected when driving at night with heat-absorbing glass. The last important group of cooperative road tests of this nature was made in February 1952, reported to this board by Val Roper in 1953, and published in Highway Research Bulletin 68. Cooperating in these tests were representatives from the State of Massachusetts, the Automobile Manufacturers Association, General Electric, and major motor car manufacturers. The tests were run at Orlando, Florida and

[1] Highway Research Board, Bulletin 68, 1953.

the 2,880 observations showed an average reduction of seeing distance with heat-absorbing windshields of 3 percent as compared with conventional windshields.

These Orlando tests generally have been accepted as correct for the conditions maintained during the tests. However, the question has since been raised as to whether the conditions were sufficiently severe to show the maximum difference in nighttime seeing distance which a driver might find under extremely adverse circumstances. Since the eye is less and less adaptable as brightness levels are reduced, it might appear possible that substitution of heat absorbing for conventional windshield glass might show a difference greater than 3 percent in seeing distance under adverse conditions such as, for example, a black object on a black-top road.

The tests to be reported here were designed to investigate this possibility, and were especially planned to make the seeing task very difficult compared to normal conditions.

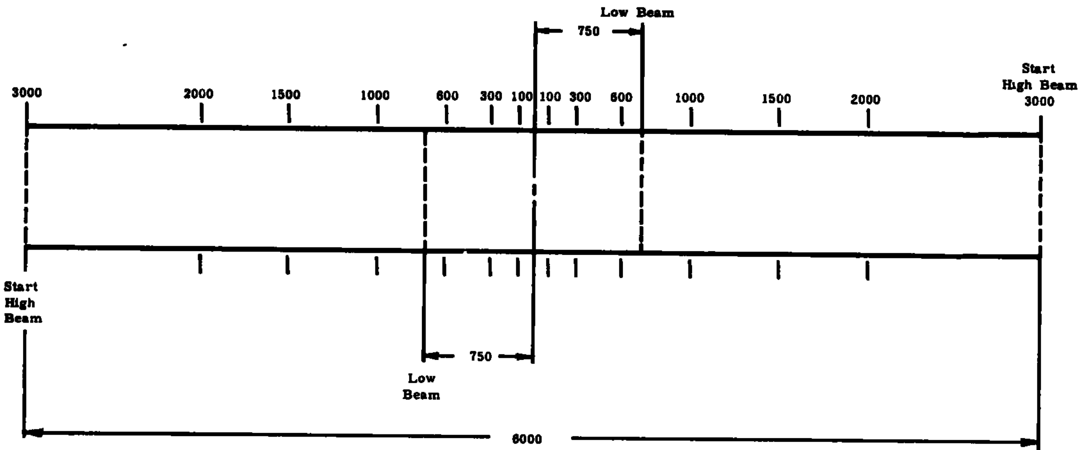


Figure 1.

They were carried on in the fall of 1953 at the General Motors Military Proving Grounds. Cooperating in the tests were the Automobile Manufacturers Association, General Electric and General Motors. We were fortunate in having Val Roper and George Meese from General Electric as consultants to assist in this extensive series of tests. Most of the test work was carried on by the proving grounds staff under the direction of Paul Skeels. Cars and windshields were furnished by Henry Boylan of the Buick Motor Division who also supervised the major part of processing the data. The authors are very grateful to Howard Gandelot of the General Motors Engineering Staff and W. F. Sherman of A. M. A. for valuable consultation and assistance. Thus it is clear that the authors are acting only as reporters for the group as a whole.

NATURE OF THE TESTS

Figure 1 shows the course used for these tests which were run with the same general procedure previously described by Roper. It was 1.2 miles long. There were twelve targets or obstacles, made to simulate pedestrians, distributed along each side of the road. These were placed on the pavement just outside the traffic lanes. The object of the test was to determine the distance at which each of these obstacles could first be detected when driving on the test course. Two cars were started simultaneously from opposite ends of the course and approached each other at a speed of 40 mph. The drivers used upper beam headlighting for road illumination until the two cars were 1500 feet apart. They then depressed to the lower beams, passed each other at the center of the course, and continued with lower beams. Thus the seeing condition immediately after passing was more critical than under normal operation when the headlamps are switched to the upper beams immediately after passing. The driver and each of the two passengers in the front seat of each car acted as observers. The point at which each target was first seen by each observer was electrically recorded on paper

TABLE 1

TEST CONDITIONS

Condition Number	Figure No.	Target Reflectance percent	Headlamps	Filament Voltage (Ave. Reading) Upper	Lower	Headlamp Aim	Date
1	2 6 to 11	7	New facing same	6. 25	6. 30	Standard	Oct. 6, 1953
2	3 12 to 17	3	Used facing same	6. 28	6. 29	Standard	Oct. 7, 1953
3	4 18 to 23	3	Used facing new	6. 12 6. 53	6. 20 6. 63	2° low 3° high	Nov. 5-6, 1953
4	5 24 to 29	3	New facing used	6. 53 6. 12	6. 63 6. 20	3° high 2° low	Nov. 5-6, 1953

tapes driven by a flexible shaft from an adaptor on the speedometer drive essentially as described in the earlier paper on the Orlando tests.

The procedure was to make six runs with a conventional windshield, six with a heat-absorbing windshield, and so on until 60 runs had been made by each car. Thus for a particular set of conditions, 30 observations through each of the two windshield types, by six observers, of twelve targets were made. This is 4,320 observations for each set of experimental conditions. It took most of a night to make a complete set of observations. Four different conditions were used on different nights making a total of more than 17,000 individual observations of seeing distance. This large number of observations was necessary because the seeing distance differences are so small that, as shown by many previous tests, it is difficult to differentiate consistently between the two types of windshields with a small number of observations. The random differences between observations will be discussed later.

TEST CONDITIONS

All the tests covered by the present paper have the following conditions in common: (1) Black top road was used. (2) Tests were run on clear, moonless nights. (3) The shoulders alongside the road were dirt with grass and weeds; reflection was very low. (4) The observation targets were made of plywood cut to the size and shape of pedestrians and carefully painted. (5) Cars were equipped with readily changeable windshields so that the conventional and heat absorbing glass could be exchanged frequently and expediently. (6) All windshields were kept free of dirt and fingerprints. (7) Luminous transmittance for all the windshields used in these tests were measured by the Libbey-Owens-Ford Glass Company as follows: Three conventional laminated plate glass: 87. 5, 87. 0, 87. 0 percent (average of 27 measurements over the whole area). Three heat-absorbing glass: 73. 3, 72. 0, 74. 3 percent (average of 27 measurements over the lower "road viewing" portions of the area). Measurements were made normal to the surface with Illuminant A.

Table 1 shows the test conditions which were varied from one set of tests to another.

1. The target reflectance was varied. Each target was painted on one side with a dark gray paint which had a reflectance of about 7 percent.[2] The other side of the target was painted with a black paint with a reflectance range between 3 and 3. 5 percent. This was the blackest paint we could find which would not readily change its gloss with handling. Table 1 shows which side of the target faced the observers in each set of tests.

2. In the first set of tests new headlamps were used. In a second set of tests,

[2] The reflectance was measured on a goniophotometer. The sample was viewed normal to the surface with the light striking the sample at 45 degrees.

TABLE 2

OBSERVERS

Observer Number	Position in Car	Vision Left	Vision Right	Glasses	Reaction Time
1	Driver	20/20	20/20	No	0.56 sec.
2	Right hand	20/20	20/20	Yes	0.47
3	Center	20/60	20/60	Yes	0.53
4	Driver	20/20	20/20	No	0.46
5	Right hand	20/20	20/20	Yes	0.59
6	Center	20/40	20/50	No	0.64

headlamps were used having previous service equal to about one-half of their normal life expectancy. This actually had a negligible effect on the illumination but the change was made in order to avoid the possible criticism that only new headlamps were employed. In fact, one of these lamps burned out during a test, showing that it was really "used." It was replaced with a previously photometered and similar half-service-life lamp. Headlamp aim and filament voltage were the same for the first two conditions (Table 1).

3. In the last two sets of tests the used headlamps were aimed two degrees below horizontal, and the new lamps two degrees above horizontal to further accentuate the differences. The voltage regulator in the car with the used lamps was adjusted to give lower voltages; in the car with the new lamps higher voltages were used as shown in Table 1.

In Table 2 is some information on the personnel who made the seeing distance observations. A variation in observers purposely was introduced into these tests in order that they would represent a wide range such as might be found among car drivers. It will be noted that two of these observers had normal vision uncorrected, two had vision corrected to normal by glasses, and two had vision below normal. Reaction times on these observers are also shown in the table. The average change in reaction

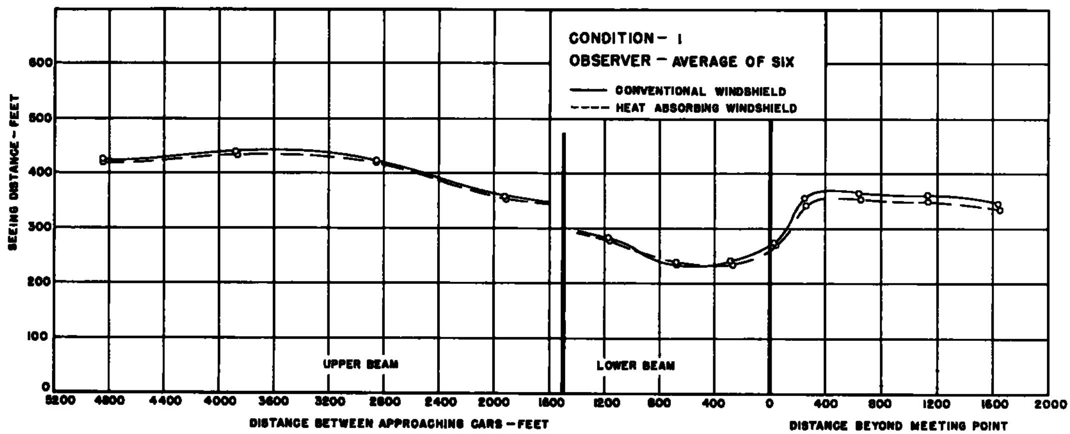


Figure 2.

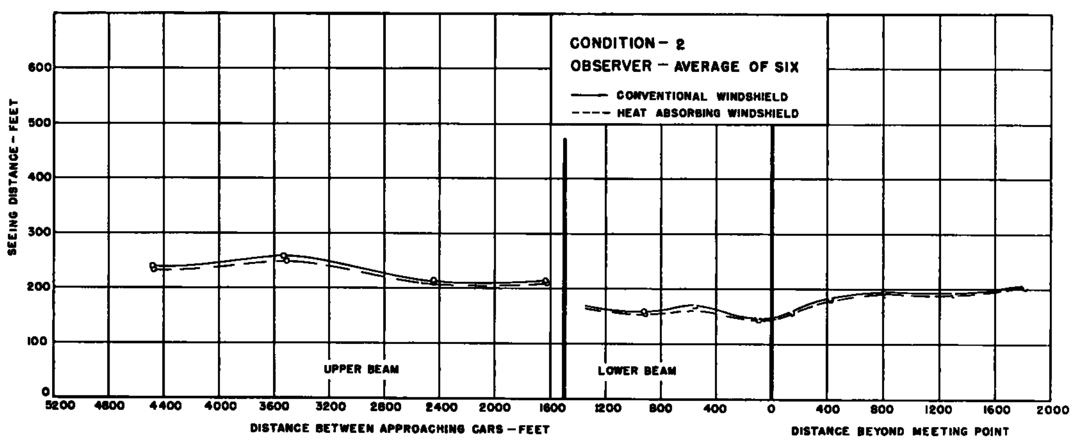


Figure 3.

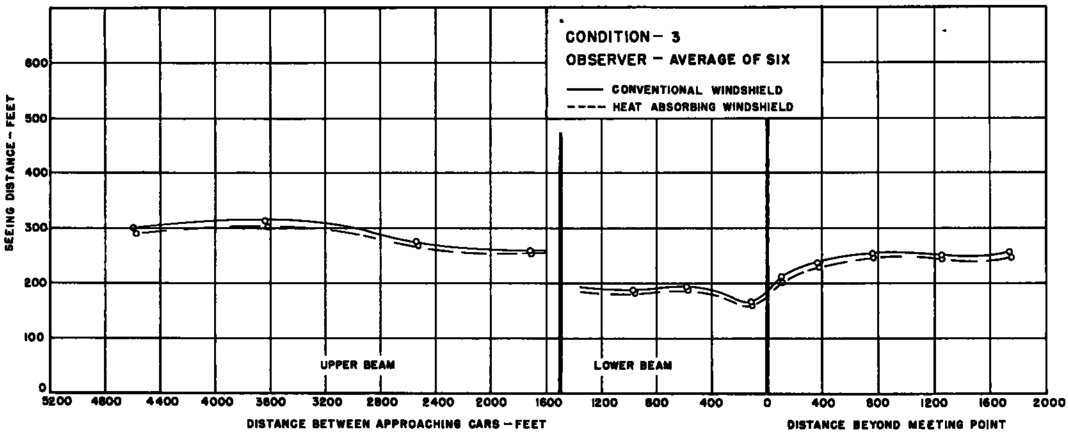


Figure 4.

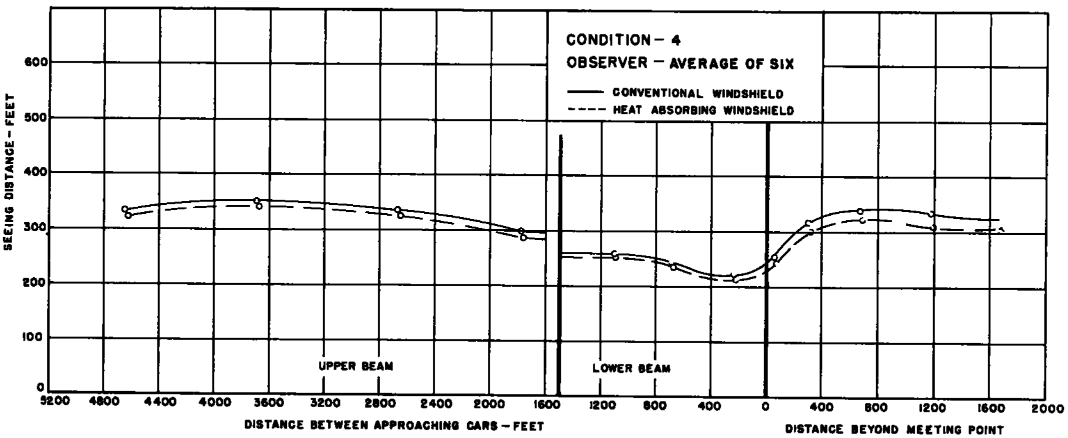


Figure 5.

time during the course of a test was less than 1 percent and changes in individual observers varied in a random manner.

The tests were started as soon as the sky turned dark and continued until about 4 AM with only one "coffee break." This meant that the observers experienced a great deal of fatigue by the end of the tests. This was done purposely in order to introduce this added difficulty into the seeing task of the observers.

SUMMARY OF RESULTS

Summaries of the test results are shown in Figures 2, 3, 4, and 5 and in Table 3. In these curves the seeing distance in feet is plotted against: (1) distance between approaching cars before they pass (left of zero on the curves) and (2) distance beyond meeting point after they pass (right of zero on curves). Each point on these curves represents the average data taken by six observers in 30 runs, that is, the average of 180 individual observations of seeing distance. The solid line represents observations through conventional windshields, the dotted line, through heat-absorbing windshields.

TABLE 3

SUMMARY

Average of All Observers and Targets				
Condition	Seeing Distance ft.		Difference	
	Conventional	Heat Absorbing	ft.	%
1	346	340	6	2
2	195	191	4	2
3	242	235	7	3
4	303	290	13	4
			Average 3%	

Inspection of Figure 2 shows that the

first points at the left represent a seeing distance of approximately 430 feet. The two cars then were almost a mile apart and thus the effect of opposing headlights was negligible. As the two cars approached, and the glare from opposing headlights increased, seeing distance began to drop off. There was a sudden change in seeing distance when the two cars were 1500 feet apart. This was due to depressing the headlight beams at a greater than normal distance and thus suddenly decreasing the illumination on the targets. The effect of opposing headlights caused seeing distance to decrease as the cars approached each other, reaching a minimum of about 230 feet just before they passed. It then rose to about 360 feet and the curves leveled off.

The important thing to observe in Figure 2 is the very small difference between seeing distance through conventional and heat-absorbing windshields. The seeing distance averaged over all targets and observers on this test course changed from 346 to 340 feet — a change of only 6 feet in 346 or 2 percent. It is interesting to note that where the seeing distance is the least the two curves are very close together. The maximum spread between the two curves is at the right hand end where the difference is about 4 percent.

These results in Figure 2 are in very close agreement with the earlier tests performed at Orlando which showed 3 percent difference in seeing distance with targets having the same reflectance. There is certainly no indication that the change in contrast, brought about in the present tests by using a black-top road instead of white concrete, appreciably affected the difference in seeing distance through the two types of windshields.

Figure 3 shows the average curves for the second set of conditions in which blacker targets were used. It will be noted that decreasing the reflectance of the targets from 7 to 3 percent reduced the seeing distance through both windshields very considerably from Figure 2. The first target was first seen at about 240 feet instead of 420. Although the curves in Figure 3 are flatter than in Figure 2, there was a definite decrease in seeing distance as the cars approached each other. Minimum seeing distance was about 150 feet. It is most important to observe, however, that the curves for conventional and heat-absorbing windshields still lie very close together. The average difference between the two windshields under Condition 2 was 4 feet in about 200 or 2 percent as shown in the Summary Table 3. This result is especially significant because the seeing task imposed upon the observers while taking the data in Figure 3 was far worse than would be experienced in ordinary night driving. The targets were very dark and the contrast so small that without benefit of headlights on these dark nights a target could not be seen by an observer walking down the road until he was within a few feet of it.

The comparison of Figures 2 and 3 shows principally the effects of reducing the contrast between target and background. The change in headlamps between these sets of runs had little effect on the illumination. Table 4 shows that at 200 feet the illumination changed from 1.55 to 1.3 ft. candles or 16 percent. The average change was probably less. This and other details of Table 4 will be discussed under the heading Photometric Measurements. Although headlight illumination underwent little change, the brightness of the targets themselves was markedly reduced by substituting 3 percent for 7 percent reflectance paint. Thus it was principally the contrast between target and background that was reduced.

Conditions 3 and 4, listed in Table 1 were designed to determine the effect of reducing illumination from the observer's headlights and increasing glare from opposing headlights, while holding the contrast essentially constant at the same low value maintained for Condition 2. It was decided to make this change in headlight illumination realistic by holding it within a range that might be expected with modern headlights. Changes in voltage and aim are considered as large as could reasonably be expected in service.

It is clear from Table 1 that a difference in glare between Conditions 3 and 4 was achieved by establishing different headlight conditions for the two approaching cars. Observers in both cars took data, in one car under Condition 3, and in the other under Condition 4. On the next night the observers and conditions were interchanged and the remainder of the data taken.

Figure 4 shows the results obtained under Condition 3 of Table 1. It was anticipated

TABLE 4

PHOTOMETRIC MEASUREMENTS

(Made through windshields from driver's eye position at 200 feet from target)

Condition	Target Reflectance percent	Beam	Brightness (ft. - lamberts)					Illumination (ft candles)
			Target	Background		Pavement	Shoulder	
				Left	Right			
(New Headlamps)								
Heat-absorbing	7	High	.103	.006	.020	078	013	1 55
Conventional	7	High	.073	.009	.016			
Average			.090	.008	.018			
				C = 10	C = 4	C = 0.1	C = 6	
(Used Headlamps)								
Heat-absorbing	3	High	032	.017	.028			1.3
Conventional	3	High	.038	.024	.038			
Average			.035	.021	.033			
				C = 0 7	C = 03			
(New Headlamps)								
Heat-absorbing	7	Low	.014					
Conventional	7	Low	.010		.007			
Average			.012		.007			
					C = 0.7			

$$C = \text{contrast} = \frac{\text{target brightness} - \text{background brightness}}{\text{background brightness}}$$

that the shortest seeing distance would be obtained under this condition. Actually the seeing distance was greater than under Condition 2 as shown in Table 3. The reason is not known but it should be pointed out that the tests under Conditions 3 and 4 were made a month later than those under 1 and 2. This lapse of time was required to obtain similar moonless nights. In any case, the comparison of the first two conditions with the second two is not important. It is intended rather to compare data taken under Conditions 3 and 4, summarized respectively in Figures 4 and 5.

Figure 4 shows the average results of observations made in the car with reduced headlamp voltage and with lamps aimed low. The average difference between the two curves is 7 feet in 242 or about 3 percent.

The data in Figure 5 were taken from the car having somewhat greater headlight illumination. Average seeing distance was about 60 feet, or 25 percent greater in this car than in the opposing car represented by Figure 4. The important fact is that the reduction in seeing distance with heat absorbing, as compared with conventional windshields is comparable under Conditions 3 and 4 as shown in Table 3.

It should be pointed out that it is unnecessary to run seeing distance tests with further reductions in illumination such as might be obtained with poor or obsolete headlamps. This is because all cars which manufacturers equipped with windshields of heat-absorbing glass also were equipped with sealed-beam headlamps which provide good highway illumination and little change in beam candle power output during their service life.

EXAMINATION OF DATA FROM DIFFERENT OBSERVERS

The curves in Figures 2 to 5 represent the data for four conditions averaged over six observers and thus summarize the results. The examination of the corresponding curves for each observer is also of interest. These curves are shown in Figures 6 to 29 assembled at the end of this paper. A comparison of data from different observers operating under one condition may be made with curves on a single page. Comparison of results from a given observer under different conditions may be made by comparing curves opposing each other on facing pages.

Visual comparisons by the authors have led to the following observations:

1. The seeing distance under a given set of conditions varies with the vision of the driver: drivers 1 and 4 with 20/20 vision uncorrected see the targets at the greatest distances; observers 2 and 5 with corrected vision, at lower distances; observers 3 and 6 with poorer vision, at slightly lower distances than observers 2 and 5 in some cases, and nearly the same in others. It should be pointed out that another variable besides vision enters this comparison, namely, observer position in the car. The data

do not allow separation of effects of vision and position because observers occupied the same positions throughout the tests.

2. Reducing target-to-background contrast (Condition 1 to 2) reduces the seeing distance by comparable amounts for all observers.

3. The changes in going from Conditions 3 to 4 which increased illumination from the observers headlights and decreased glare from the opposing headlights results in some increase in seeing distance for all observers, but the increase appears to be greater with observers 1 to 3 than with observers 4 to 6.

4. The difference in seeing distance between conventional and heat-absorbing windshields does not appear, from visual inspection, to be markedly or consistently affected either in direction or magnitude by changes in conditions or observers.

A. The seeing distance with heat-absorbing windshields is slightly less than with conventional in all Figures 6 to 29 with the single exception of Figure 9 where the seeing distance with heat-absorbing windshields is slightly greater over most of the test course. Occasional crossovers in other curves are probably a result of random variations which appear in the mean values even though each point in these figures represents the mean of 30 observations. (See the later discussion of Table 5.)

B. The magnitude of the difference varies from one pair of curves to another but not in a manner which appears from visual inspection to be related consistently to experimental conditions or observers.

TABLE 5

SAMPLE OF ORIGINAL DATA

Target 1, Condition 1, Observer 1

Observed Seeing Distance (ft.)		Ave. in sets of 6 (ft.)		
Conventional Windshield	Heat Absorbing Windshield	Con	H A.	Difference
454	544			
530	495			
540	535			
502	500			
530	495			
525	520	514	515	-1
562	450			
557	480			
479	480			
509	478			
517	480			
524	508	525	479	+46
450	541			
510	542			
472	447			
426	422			
562	394			
496	480	486	471	+15
513	516			
434	537			
458	450			
501	486			
409	521			
512	497	471	501	-30
501	523			
423	490			
535	516			
535	544			
478	460			
565	515	506	508	-2
Average 500	495			
Std. dev. 44 ft.	37 ft.			
Difference 5 ± 11 ft.				

EXAMPLE

Std. dev of individual readings =

$$\sqrt{\frac{\Sigma(454-500)^2 + (530-500)^2 + \text{-------} + (565-500)^2}{(30-1)}}$$

Std [a] error of mean difference = $\sqrt{\frac{44^2}{30} + \frac{37^2}{30}} = 11$ ft.

[a] See for example "Applied Mathematics in Chemical Engineering" Sherwood and Reed.

5. It is very difficult by visual examination to draw definite conclusions about the effect of glare on the difference between seeing distance with the two windshields. In some cases the curves are closest together near the minimum points where glare is greatest but visual inspection does not establish this as a general effect.

STATISTICAL EXAMINATION OF THE DATA

It is well to point out again that each of the plotted points in Figures 2, 3, 4 and 5 represents an average of 180 individual observations of seeing distance. Each of these figures then represents the result of 4,320 observations. It is only by making a very large number of observations that curves can be obtained showing so little scattering of points. The importance of having a large number of observations and the statistical significance of these data will now be discussed briefly.

Individual observations of seeing distance made by one observer, under one set of conditions, on one target, show large random variations from one run to another. In some cases this variation may be as great as 2 to 1. In order to examine the nature of these variations more closely, Table 5 presents two columns of 30 readings each, taken by observer 1, on target 1, under Condition 1. The first column presents 30

TABLE 6

AVERAGE SEEING DISTANCE DATA FROM ALL TESTS

D = Average of 30 observations of seeing distance through conventional windshield.
Δ = Difference of average seeing distance (conventional - heat abosrbing).
[a] Difference is minus.
Where no value is entered difference is zero.
σ = Average standard deviation of individual readings (60°).

Target	Condition	Observer 1 D	Observer 1 Δ	Observer 1 σ	Observer 2 D	Observer 2 Δ	Observer 2 σ	Observer 3 D	Observer 3 Δ	Observer 3 σ	Observer 4 D	Observer 4 Δ	Observer 4 σ	Observer 5 D	Observer 5 Δ	Observer 5 σ	Observer 6 D	Observer 6 Δ	Observer 6 σ
1	1	500	5	41	374	8	55	343	16	40	494	16[a]	43	450	9[a]	38	405	10	40
1	2	299	1	44	211	4[a]	43	221	4	34	263	11	31	217	10	38	222	6	48
1	3	342	19	42	262	19	34	273	13	28	348	11	41	289	16	44	289	5[a]	36
1	4	413	8	47	301	31	38	313	18	36	359	14	38	314	14	30	314	3	28
2	1	507	7	24	395	16	42	355	4	42	506	8[a]	43	463	1[a]	28	420	6	30
2	2	301	5[a]	39	244	11	38	235	6	30	267	3	46	255	15	42	245	12	43
2	3	342	17	35	281	25	36	267	7	32	356	6[a]	44	312	3	25	319	1	33
2	4	430	4[a]	29	323	21	46	334	9	33	362	30	33	321	15	28	331	1[a]	26
3	1	499		21	398	11	55	326	2[a]	27	484	3[a]	32	434	13	40	399	6[a]	44
3	2	260	4	36	196	13	37	198	6[a]	41	215	2	30	194	2	30	207	1	30
3	3	305	7	44	268	21	50	255	16	39	312	3	25	255	5[a]	39	272	5	31
3	4	428	8	49	318	17	58	301	10	28	343	10	34	313	10	36	310	11	35
4	1	404	5[a]	32	325	6	28	301	14	26	405	10[a]	30	384	9	29	360		32
4	2	260	3[a]	37	188	1	31	187	1[a]	39	228	11	30	206	11	31	196	3	36
4	3	275	17	25	231	6	23	229	15	19	304	4	22	254		24	265	3[a]	17
4	4	348		32	273	2	27	277	15	24	328	20	22	286	15	32	289	4	25
5	1	333	4	43	272	10[a]	56	245	3	34	283	11[a]	34	303	16	36	294	12	24
5	2	185	7	32	153	5[a]	31	142	2[a]	27	162	6	35	155	6	21	163	4	25
5	3	206	9	19	206	10	29	168	1	24	197	7	21	188	3	23	191	7[a]	30
5	4	290	3	27	261	4[a]	33	238	2	22	261	16	21	274	16	26	265	12	27
6	1	255	2	22	226	5	27	189	1	17	233	10[a]	23	241	1[a]	18	238	11[a]	23
6	2	182	11	37	166	9	32	143	6	30	168	11	41	177	12	35	181	4	37
6	3	217	18	26	210	16	22	174	4	22	187	6	32	199	3[a]	28	192	5[a]	26
6	4	266	18	27	252	4	24	238	28	20	298	13	17	248	4[a]	25	255	10	18
7	1	253	3	30	225	6	24	213	5	19	222	2	38	268	12	21	259	7	21
7	2	149	1	28	146	2[a]	25	137	6	28	141	3	30	150	5	26	163	6	23
7	3	166	10	19	175	7	19	153	8	17	148	4	21	172	3[a]	17	172		19
7	4	252	17	40	229	6	26	195	5	27	191	1	38	242	21	19	244	24	23
8	1	281	1	19	270	4	25	252	13	28	264	7[a]	36	298	9	23	302	2	26
8	2	178	4[a]	30	161	3	27	154	3	27	161	8	27	158	4	23	174	3	24
8	3	220	15	17	212	12	16	182	4	16	195	1[a]	22	211	1[a]	17	223	14	14
8	4	275	18	25	254	1[a]	28	239	18	15	255	9	23	284	7	16	286	13	21
9	1	385	7	24	359	33	36	322	25	36	324	6[a]	44	385	17	33	376	23	35
9	2	198	2[a]	32	179	3	30	168	4[a]	28	181	8	26	183	2	22	192	10	28
9	3	252	8	19	245	19	22	204	16	21	217	1	21	250	8	19	236	7	20
9	4	335	15	26	301	15	28	284	27	28	313	16	23	321	1[a]	26	324	17	23
10	1	417	3	26	371	23	32	314	22	41	352	16	50	392	11	34	378	2	35
10	2	213	4	32	187	2	31	176	1	32	198	13	27	200	2	27	201	5	29
10	3	272	8	21	253	18	17	224	18	20	247	4	23	268	4[a]	17	259	10	11
10	4	384	17	55	341	14	51	312	26	51	315	10	28	340	11	32	326	16	30
11	1	449	25	43	366	12	42	292	15	24	343	8	40	391	22	43	358	2	29
11	2	210	6	32	181	1[a]	29	168	8[a]	31	198	5	24	200	2	25	205	12	27
11	3	280	11	20	260	15	36	221	14	22	243		28	267	3	21	249	2	24
11	4	375	11	57	332	24	41	294	15	44	318	20	26	345	23	29	325	17	34
12	1	409	8	37	359	18	36	281	16	27	358	17	36	381	9	24	352	9[a]	34
12	2	222	2	29	196	7	30	180	1[a]	28	208	5	32	210	1	25	212	4	28
12	3	271	2	22	268	11	19	234	15	19	257	17	19	261	10	18	265	16	14
12	4	360	14	49	349	20	42	286	10	39	311	11	35	326	19	25	323	22	32

observations through a heat-absorbing windshield. A standard deviation for each column has been obtained as shown in the table to express the random errors in the individual readings. Assuming normal distribution, the standard deviation means, for example, that there is a 68 percent probability that another reading taken under the same conditions as the data in Column 1 will lie within the range 500 ± 44 ft.

The difference in average seeing distance as deduced from these 60 readings is 5 feet and the standard error of this difference is 11 feet. From this we can say that there are 68 chances out of 100 that the correct value of the difference lies within the band 5 ± 11 ft., or between -6 and +16 feet (this statement assumes that all errors are entirely random). It is noteworthy that even with 30 readings through each windshield on this one target, there is still uncertainty as to whether the seeing distance is greater with conventional or-heat absorbing glass.

The necessity of taking such a large number of readings is further illustrated by the figures on the right side of Table 5. It will be recalled that the readings were taken in sets of six alternately with the two windshields. In Table 5 each set of six has been averaged for the two windshields and the differences obtained. A comparison of the five values of difference, each obtained with a set of six readings, is most interesting. It will be noted that the difference varies from +46 to -30 feet. Thus, had only six readings been taken, one might have drawn the conclusion that the seeing distance was 46 feet greater or 30 feet less with the conventional than with the heat-absorbing windshield, depending upon which set of data one happened to take.

It is thus apparent that accurate conclusions with regard to the seeing distance through these two types of windshields can not be drawn from a small number of observations. Even 30 observations through each windshield are not enough to answer the question, "Which windshield gives the greater seeing distance?" It is for this reason that twelve targets and six observers were used, thus multiplying the data shown in the left of Table 5 by 72 for each condition.

Stated another way, the difference we are trying to measure is so small that it is completely submerged by random variations even when every effort is made to hold test conditions constant.

Table 6 presents the data from all of these tests. This is a direct print-out from the I. B. M. machine. An effort has been made to reduce the table to the smallest number of entries which can be made and still provide all of the data necessary to carry on statistical studies of the results. Entries are arranged according to target number, condition and observer. For example, the three entries in the upper left hand corner 500, 5 and 41 summarize the data in the first two columns of Table 5. The seeing distance through the conventional windshield, 500 feet, and the difference, 5 feet, allow the seeing distance through the heat-absorbing windshield to be derived.

The third number 41 feet, in the illustrative set is an average standard deviation. This is caluclated from two standard deviations, one for the conventional and one for the heat-absorbing windshield to give an average standard deviation for the 60 readings as follows:

$$\sqrt{\frac{44^2 + 37^2}{2}} = 41.$$

Inasmuch as the standard deviations in observations on a given target, under a given condition, by a given observer, have nearly the same values for the two windshields, it is felt that average standard deviations calculated in this way for the 60 readings may be used with either set of 30 readings without altering the significance of statistical studies.

The standard error of the difference may be calculated from this average value of standard deviation as follows:

$$41\sqrt{\frac{2}{30}} = 11$$

There are some other very interesting questions that can be answered by these data. To answer these questions the data have been studied by a statistical procedure known as the analysis of variance. This procedure is valuable because it separates the effects of experimental variables in such a way that their significance can be tested independently of each other. The details of this study will not be included herein but some of the results may be summarized by the following statements:

1. The two values 6 feet and 4 feet in Table 3, representing difference in seeing distance with different target contrast, are significantly different. To be more specific it can be stated that if these average values of difference were redetermined under identical conditions and with the same number of tests there is less than one chance in a thousand that the difference, in feet, for Condition 2 would be larger than for Condition 1.

2. The two values 7 feet and 13 feet in Table 3, representing difference in seeing distance with different illumination and glare, are significantly different. If these average values of difference were redetermined under identical conditions and with the

same number of tests there is less than one chance in a thousand that the difference in feet for Condition 3 would be larger than for Condition 4.

3. The average values of difference in seeing distance between conventional and heat-absorbing windshields vary significantly and systematically with target position. The differences decrease as the cars approach, reach a minimum just after changing from upper to lower beams, and then increase.

4. In trying to study the difference between observers, no way has been found with the present data of separating the variables such as, eyesight, eye glasses, position in car, and car occupied.

THE SIGNIFICANCE OF THRESHOLD VALUES

In discussions of the possible consequences of a small difference in seeing distance with different windshields, one important point is frequently not fully recognized. The point to be emphasized is that the "seeing distances" which have been determined in these tests and which are plotted in curves 2 to 29 represent threshold values. While the term "seeing distance" commonly has been applied, a more descriptive term would be the "threshold seeing distance." The meaning of these threshold values must be clearly understood for any discussion of the importance of the results described in this paper.

In order to explain the significance of these thresholds let us set up a hypothetical case in which two cars are driving side by side down a highway at 40 mph. One is equipped with a conventional windshield, the other with a heat-absorbing windshield. Let us suppose that an obstacle is on the highway and, although it is not yet visible to either driver, that both drivers are looking toward it as they approach the threshold seeing distance. Next, assume that the driver looking through the conventional windshield first sees the obstacle at a distance of 200 feet. If the difference in seeing distance between the two windshields is 3 percent the driver of the car with the heat-absorbing windshield will then first see the obstacle at a distance of 194 feet. This 6 foot difference at this speed is traveled in only $\frac{1}{10}$ of a second. It is only during this tenth of a second that the driver with the conventional windshield has an advantage. It is most important to understand that this difference in the ability to detect the obstacle through the two windshields exists only during this 6 feet or $\frac{1}{10}$ second between the threshold of 200 feet through one windshield and 194 feet through the other, because at distances greater than 200 feet neither driver sees the obstacle, and at all distances less than 194 feet both drivers see the obstacle.

It was assumed in the hypothetical case just described that both drivers happened to be looking in the direction of the obstacle at the exact time the two cars reached threshold seeing distances. But under ordinary conditions the drivers might not be looking in the direction of the obstacle at that particular instant, or the obstacle might be obscured by a rise or curve in the road, or the obstacle might actually enter the road after the two drivers passed their threshold seeing distances. Then the situation would be different than described in the previous paragraph. Let us suppose, for example, that the two drivers both happened to look toward the obstacle when they were 190 feet from it. Neither driver would then have an advantage because they would both see the object at the same time. Thus, it must be remembered in appraising the importance of these test results in terms of driving safety that any loss in the distance at which objects are first detected can occur only at this "threshold seeing distance." After passing this threshold the distance at which the object is seen is identical regardless of whether the car has a conventional or heat-absorbing windshield and is, obviously, the distance between the car and the obstacle.

Therefore, the authors believe that the effect on driving safety of the 3 percent difference observed in these tests is truly insignificant.

PHOTOMETRIC MEASUREMENTS

Two types of photometric measurements were made in connection with this series of tests. First, all the headlamps were photometered and their beam patterns determined according to standard SAE procedures and it was found that they were within specifications. An integrated measurement made by photometering an integrating screen in front of the lamps showed that the used headlamps of Condition 2 gave about 5 percent less illumination than the new lamps of Condition 1. However, since the patterns were different for the two types of headlamps such a simple comparison is not too significant and the actual reduction in illumination on any given target in these tests might have been more or less than 5 percent.

The second group of photometric measurements were made at the test course on the nights of the tests. These measurements leave much to be desired in both accuracy and completeness. It was found impractical with available instruments and methods to measure the lower values of brightness of targets and backgrounds such as those encountered with lower beams at distances greater than about 100 feet. Also the time available between the end of the driving tests and dawn was not sufficient to carry out extensive photometric measurements.

Some photometric measurements are shown in Table 4 to illustrate the order of magnitude of brightness and contrast conditions used in these tests. The data at 200 feet are presented because this distance lies within the range of observed seeing distances with both upper and lower beams, and because it is short enough so that fairly consistent data could be obtained. Measurements of brightness in this table were made with a Luckiesh-Taylor brightness meter through the windshields of the test cars while holding the instrument at approximately the eye position of the driver. The object was to duplicate the seeing conditions of the driving tests. Values of brightness in the table are averages of three readings in most cases. Values of illumination were obtained using a standard white target viewed at close range. There were no approaching headlights when the measurements in Table 4 were being made.

Readings were taken through both the heat-absorbing and conventional windshields as shown in the table. The random variations in readings were large enough that the differences between measurements made through these two windshields are not consistantly different in direction. Thus it appears justifiable to average the readings in order to get more significant data for comparison purposes.

Measurement of background brightness was quite complicated and difficult. In typical laboratory experiments, where threshold visibility is being measured, it is customary to have both the background and target in the same plane. In these road tests, a vertical target was seen against a relatively horizontal background, namely, a portion of the road and/or shoulder at some distance behind the target. Another complication in determining background brightness in these tests arose from the fact that the two headlights set up a shadow pattern on the two sides of the target. This pattern varied with distance between car and target and affected the seeing task in a manner which the authors do not pretend to understand. To give an idea of what is involved, the first row of data in Table 4 shows four values of background brightness. The first two values were measured immediately to the left and right of the target. The observers found that when driving with upper beams the targets first came into view about hand-high on the dummies and when using the lower beams they first came into view about knee-high. Thus the backgrounds to the left and right with upper beams as shown in Table 4 row 1 were measured hand-high. At the left of the target the reading was in the shadow pattern. At the right, the shadow pattern was so narrow that the reading was probably outside the shadow and represented the dirt at some distance behind the target. The other two readings in row 1 represent the pavement brightness at the foot of the dummy, and the brightness of the shoulder of the road just to the right of the foot of the dummy. A number of values of contrast between target and background can thus be obtained and four values have been entered in the table. This indicates the problem which confronts the experimenter who tries to specify the contrast in such road tests.

The brightness of the target under Condition 2 with 3 percent reflection is shown in the second set of data in Table 4. The observed change in target brightness between Conditions 1 and 2 is in line with change in reflectance. It is not known why the background readings to the left and right of the target increased as compared to the first set of data but it probably was due to the shadow pattern being so narrow that it was difficult in taking the readings with the brightness meter to duplicate positions in the

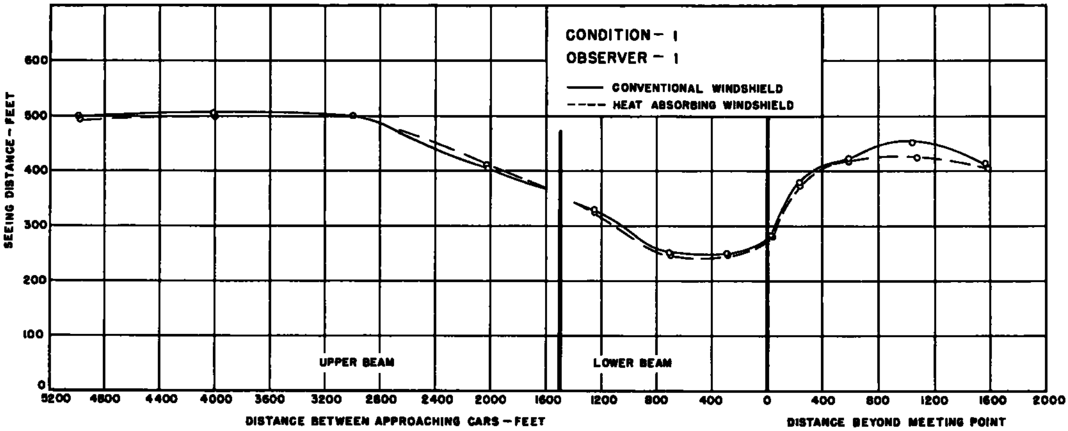
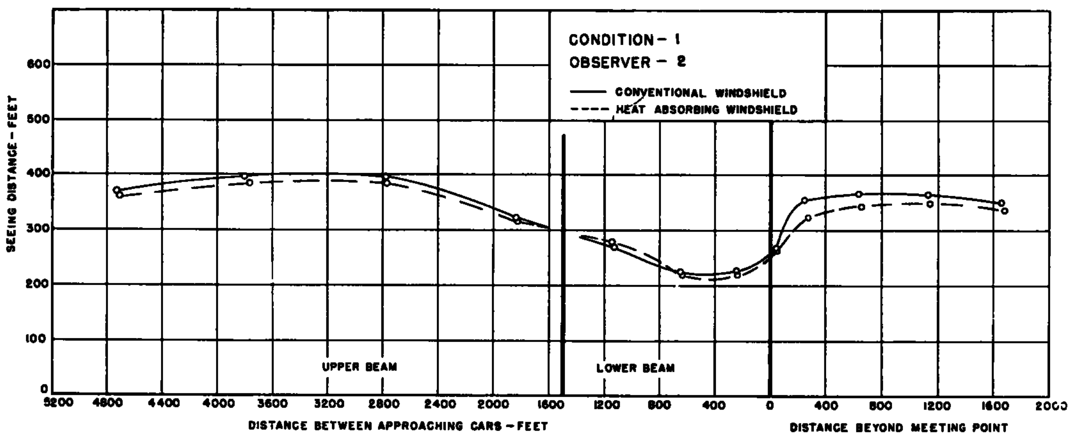


Figure 6.



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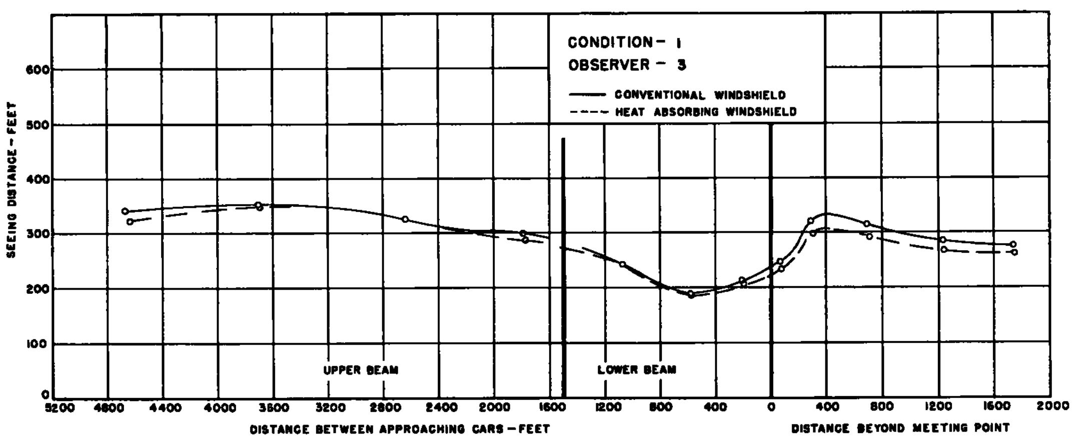

Figure 8.

background from one night to another. Large random variations due to the low brightness levels are also involved.

With the lower beam lighting, (Table 4) consistent readings could only be obtained with the 7 percent reflectance target; 3 percent targets were too dark to read at this

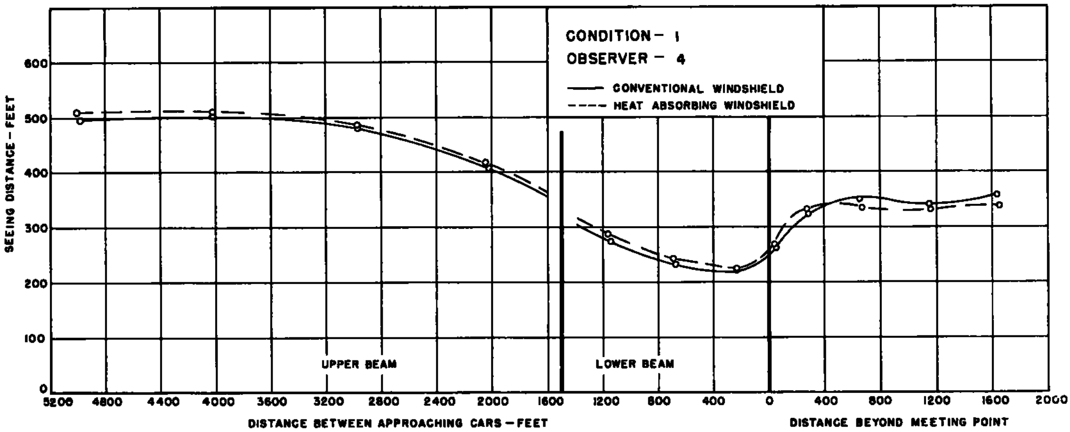

Figure 9.

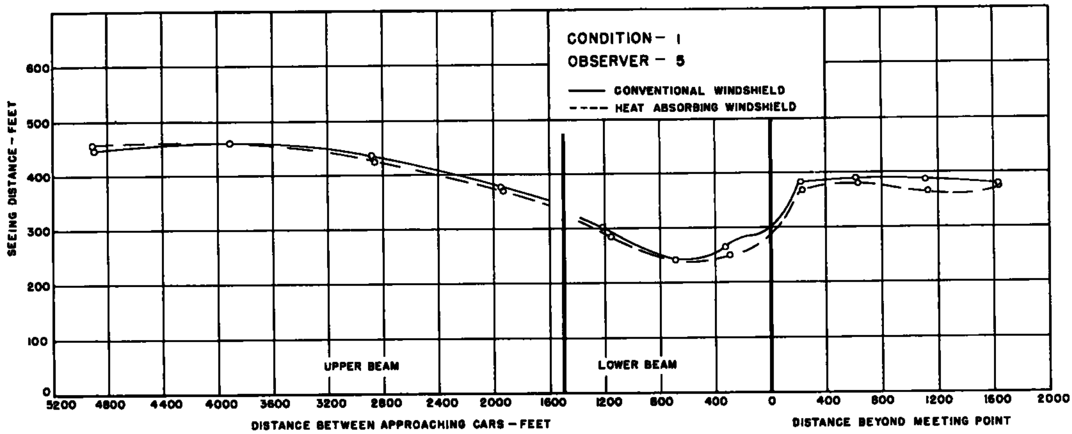

Figure 10.

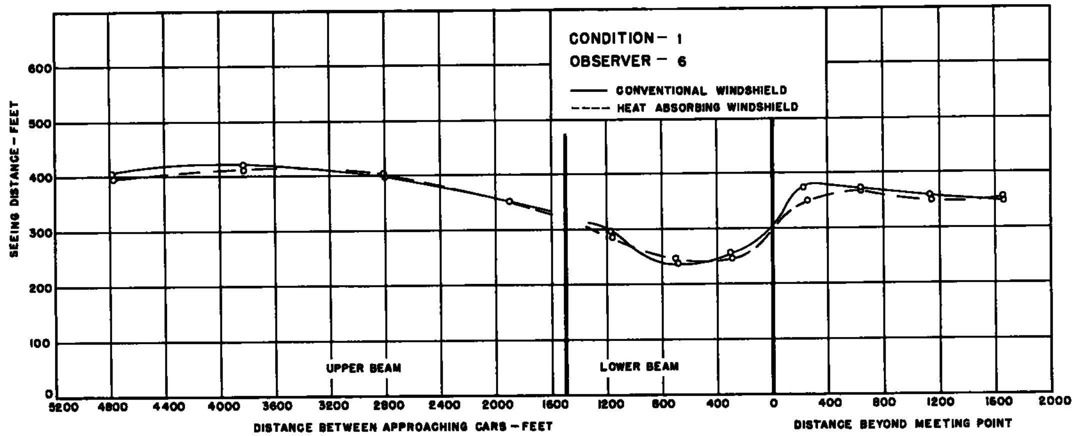

Figure 11.

distance even though they were detected by the observers in our tests. The one reading obtained on the background is too low to represent good accuracy; thus the value of contrast given under this condition is subject to doubt.

The two illumination values included in the table show that the change brought about

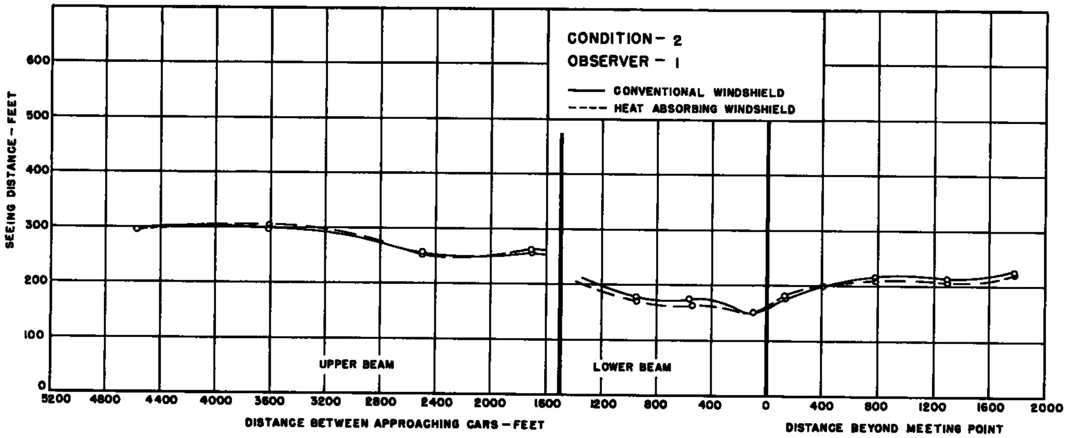

Figure 12.

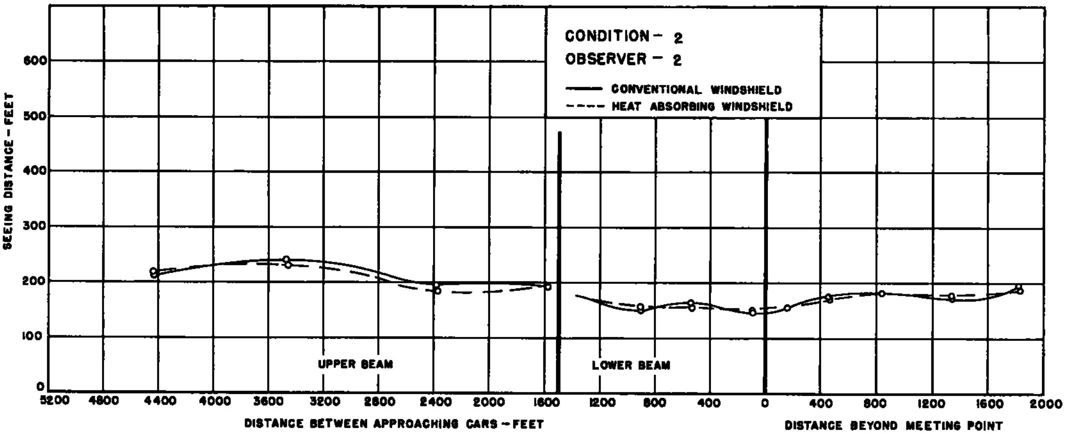

Figure 13.

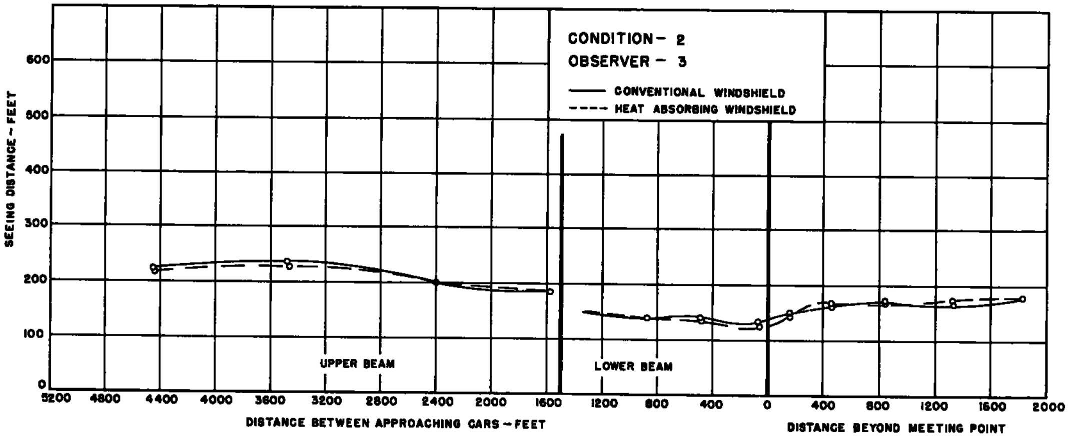

Figure 14.

by going from new headlamps to used headlamps (of a different make) was about 13 percent at this particular distance. This does not agree with the 5 percent difference between new and used lamps obtained by integrating methods, probably due to differences in beam patterns.

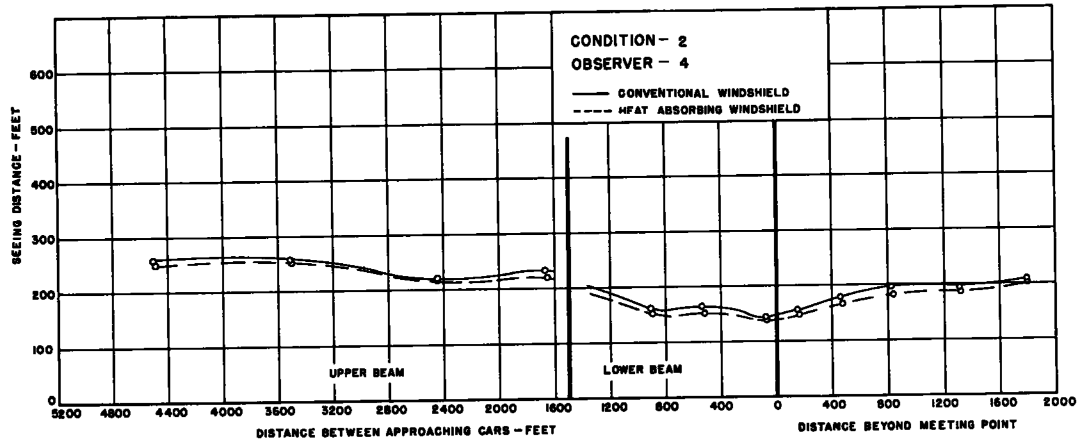

Figure 15.

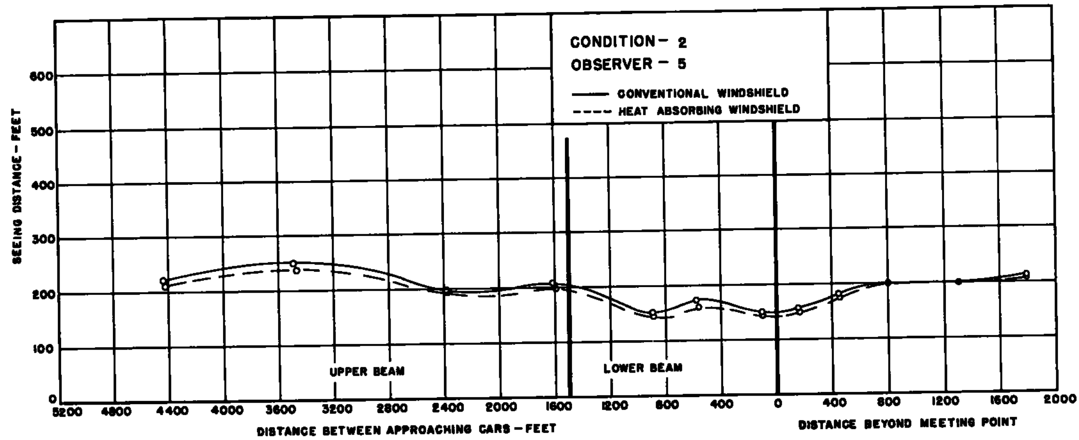

Figure 16.

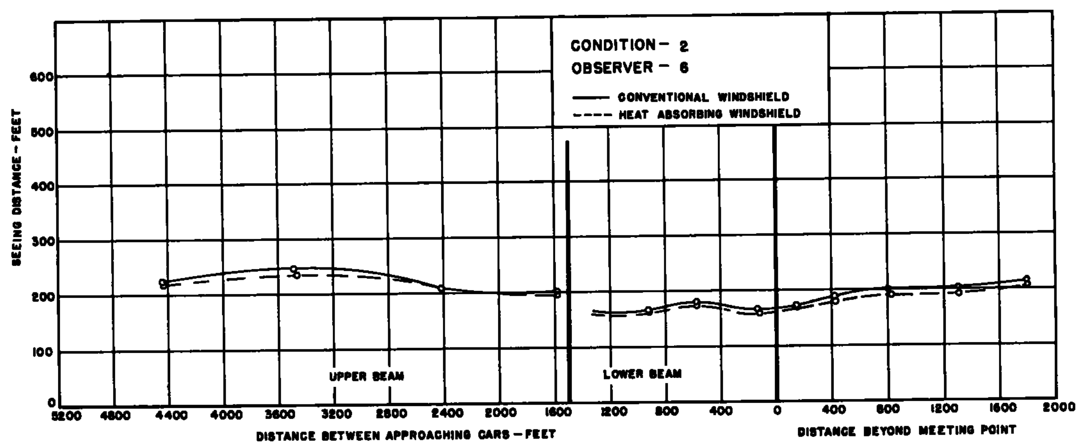

Figure 17.

The data in Table 4 show that brightness and contrast were very low even when the target was only 200 feet from the car. But measured seeing distances under many conditions were considerably greater than this with correspondingly lower target brightness. For example, with upper beams and 7 percent reflectance targets, seeing dis-

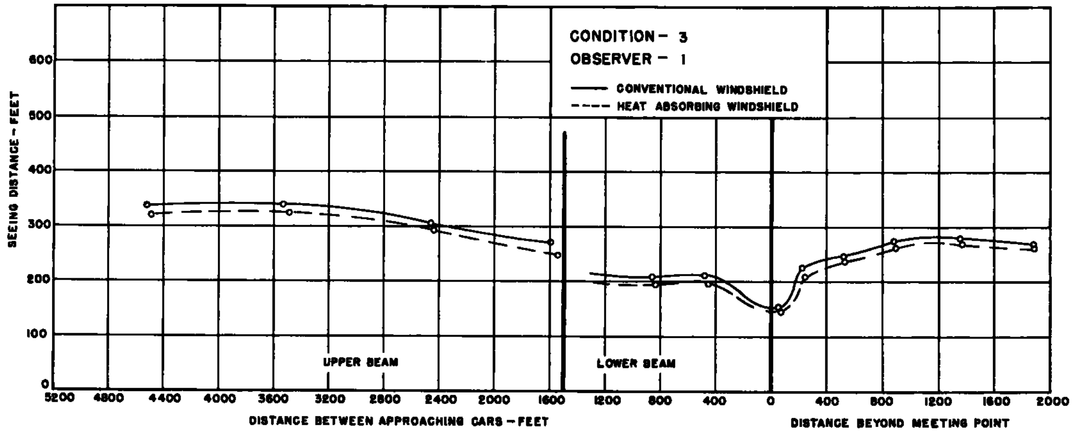

Figure 18.

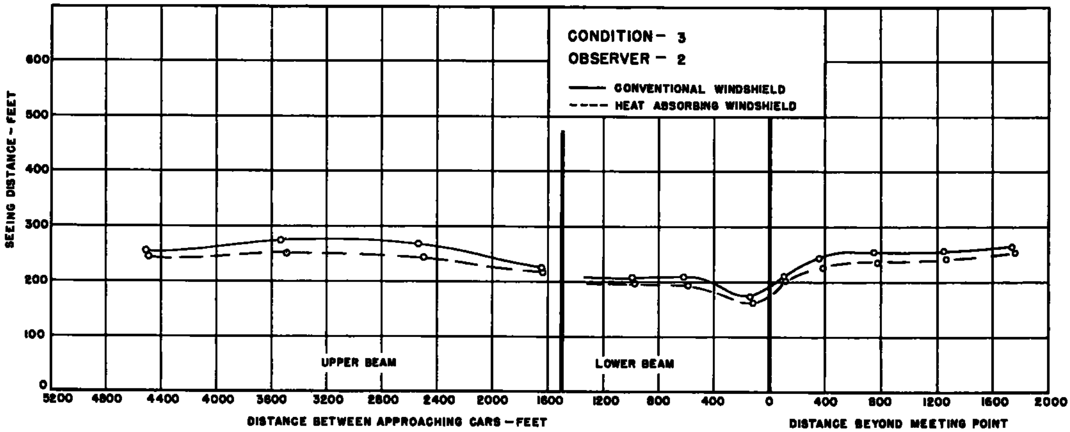

Figure 19.

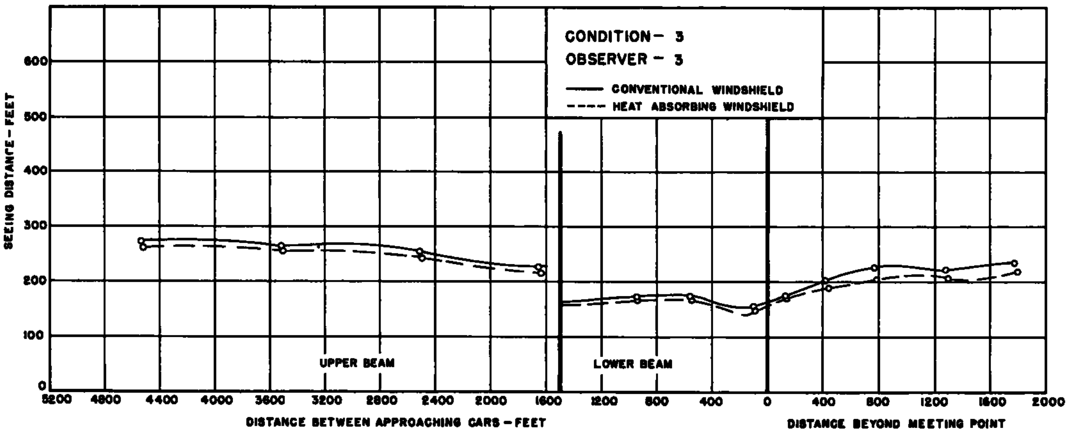

Figure 20.

tances in Figure 2, never dropped as low as 200 feet and averaged 450 feet when there was no glare interference from opposing headlights.

Target brightness at other appropriate distances and target reflectances can be calculated approximately from the data in Table 4. However, the contrast probably cannot

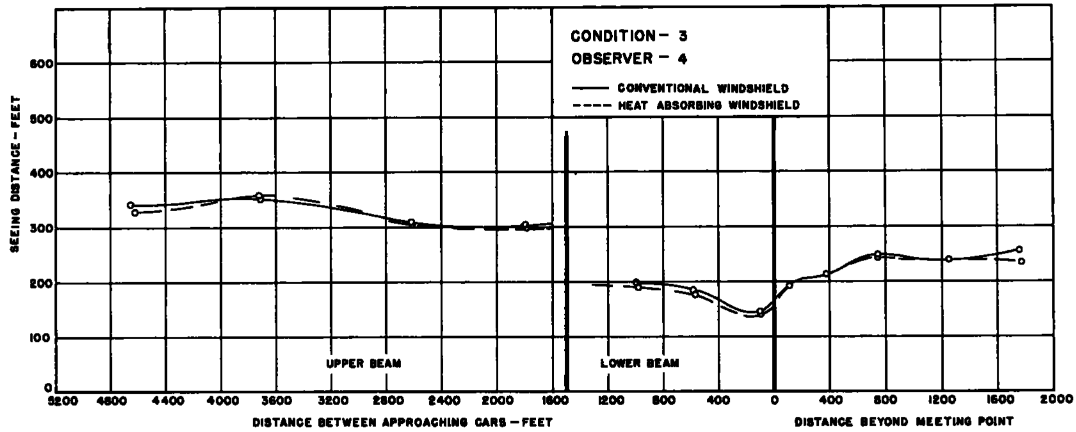

Figure 21.

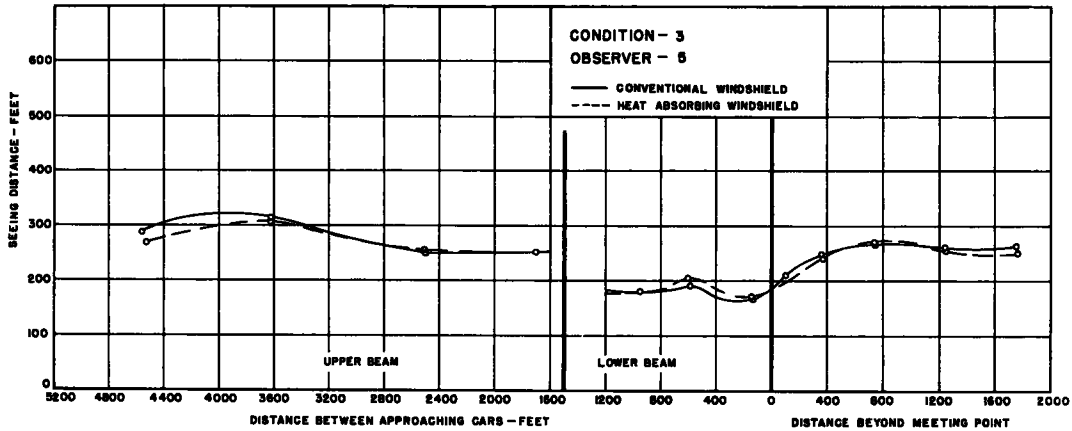

Figure 22.

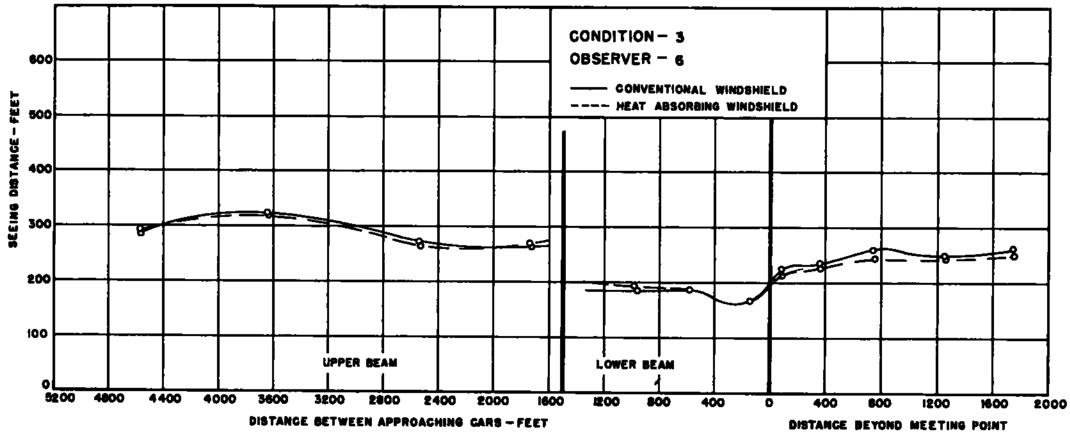

Figure 23.

be so calculated and the data obtained do not permit a very intelligent guess as to what these contrasts were.

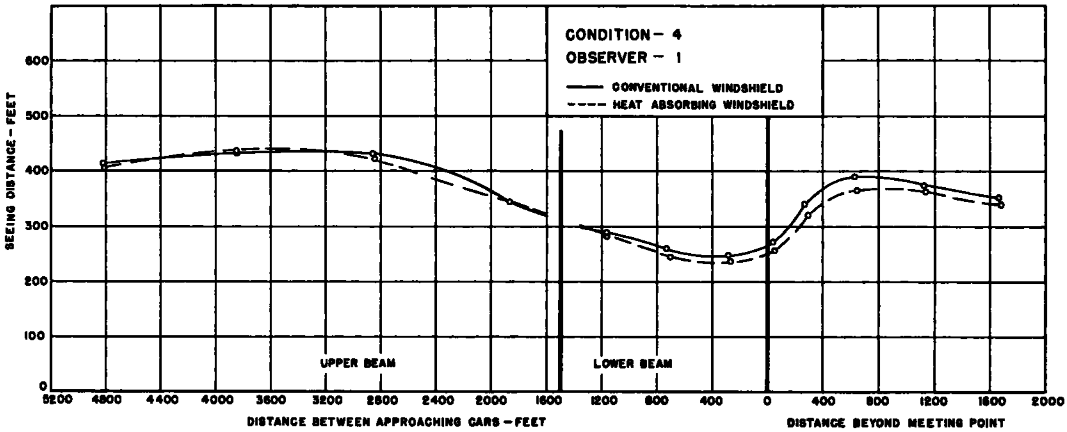

Figure 24.

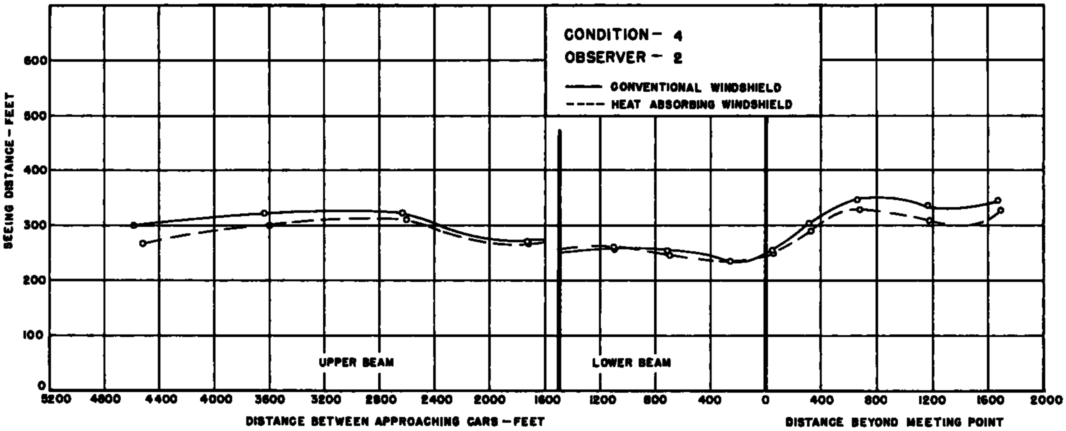

Figure 25.

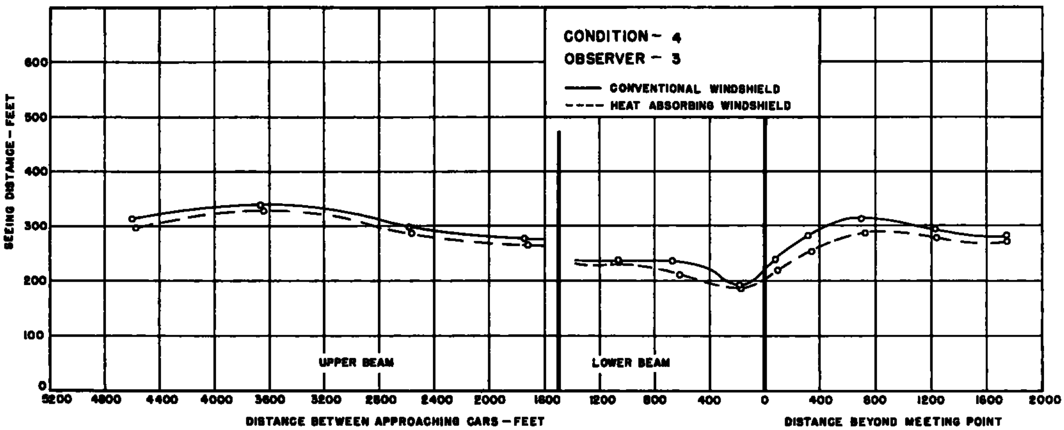

Figure 26.

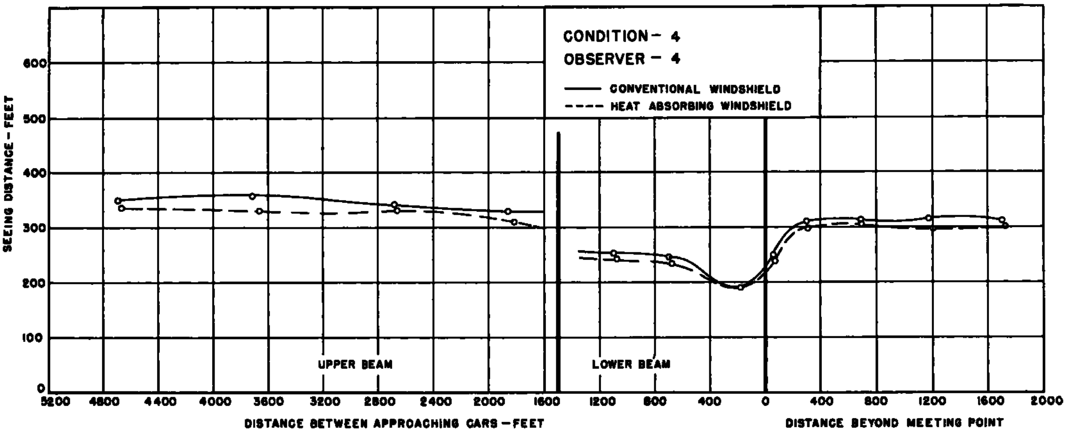

Figure 27.

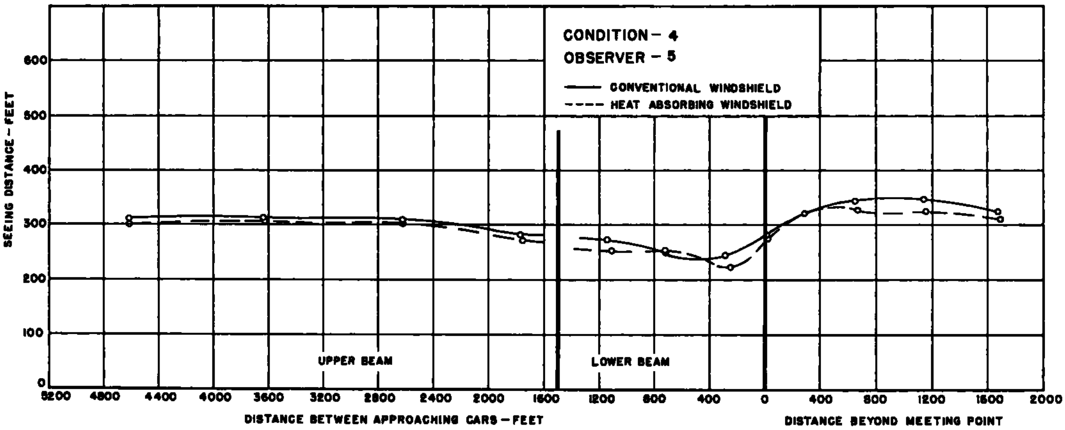

Figure 28.

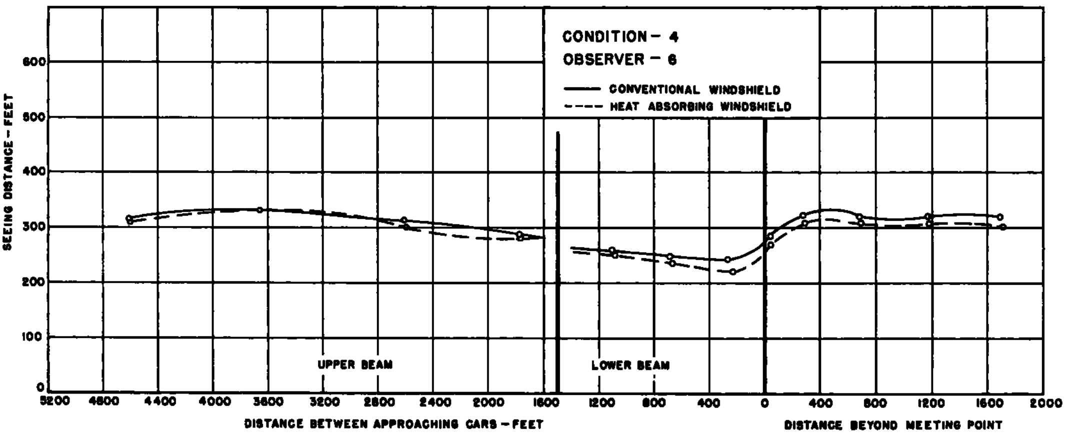

Figure 29.

CONCLUSIONS

1. In road tests of the type described in this paper the random variations between individual observations of seeing distance are exceedingly large. Thus it is necessary to make many observations under each set of test conditions before reliable conclusions can be drawn regarding differences between windshields, or regarding the effect of changing conditions on these differences.

2. More than 17,000 observations have been made in these tests to reduce to a negligible amount the uncertainties due to random variations. Repeating the same tests would not result in significantly different average values.

3. The average reduction in nighttime seeing distance observed in these tests on changing from conventional to heat-absorbing windshields was 3 percent.

4. This is in agreement with earlier road tests described by Roper.

5. The test data show no consistent trend toward any greater reduction in seeing distance even when illumination and target contrast are reduced to make the seeing task very difficult.

6. The data indicate that the reduction in seeing distance with heat-absorbing glass is not affected consistently by good or poor eyesight.

7. For the driver of a moving car, the 3 percent difference exists only at the instant of "threshold seeing" when the object is just coming into view. From then on, the driver can see the object through a heat-absorbing windshield at the same distance as through a conventional windshield.

8. A change in average night driving speed of only 3 percent would completely compensate for the observed change in threshold seeing distance. The authors believe that drivers generally adjust their night driving speeds to values which they consider safe under existing conditions including visibility, and thus on the average they may automatically apply this correction.

Discussion

OSCAR W. RICHARDS, American Optical Company, Research Center, Southbridge, Massachusetts — The fundamental problem in relating the laboratory and road tests is equating the variables, as other basic data for the eye hold for varying conditions. The laboratory work is freely questioned. As the only member of the laboratory group present, some comment seems called for.

The Cooperative Road Test seems planned to produce small differences. The driver had no competition other than the approaching car. The positions of the dummys were fixed. No randomization of observers or targets was done. The seeing distance curves are crowded together on the graphs (a well known statistical technic for minimizing differences). Many experiments were made to average out considerable variation. The usual technics of psychological research for measuring thresholds and visual phenomena were apparently not used.

This experiment seems to me to be essentially a learning experiment, where, despite a great deal of practice there remained a small difference when the clear and tinted windshields were used. It is possible that various clues at each target were part of the recognition. To make it a visibility test the targets, observers, etc. should be randomized. Since information is added in proportion to the square root of the number of measurements, it is possible that a smaller number of experiments that could be done in available time, might be more definitive than trying for great numbers.

Although done outdoors, driving under the protected conditions of this experiment hardly is equivalent to usual auto driving. A well planned test under various road conditions may yield information that can be related to the use of the eyes indoors. A wider range in age and visual defects that closely represents the driving public, should be used.

HARRY C. DOANE and GERALD M. RASSWEILER, Closure — The authors hope that future work will help to clarify the relationship between road test results and laboratory data. At present the only way we know of duplicating driving conditions is by means of road tests and thus we must depend on such tests to give us information of the type described in this paper. Many road test variations of the type suggested by Richards were carefully considered by the committee who did the planning. This group had the benefit of direct knowledge of previous tests. They felt that most of the suggestions would lead to greater random variations in the data and might completely submerge the small differences observed between the two windshield materials.

Tests certainly were not planned to minimize the differences. On the contrary, the seeing task was made very difficult, as described in the paper, to accentuate any difference which might appear.

With regard to effects of "learning," an examination of the data, such as is illustrated in Table 5, shows no consistent change in the "differences" observed as the test proceeded.

The possibility of "clues" seems remote in view of the uniformity of the road and shoulder over the length of the test course and because the darkness of the moonless nights allowed no extraneous objects to be seen.