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[Unclassified Title]

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C. F. WINGQUIST, AND A. G. ROCKMAN

Radiometry Branch
Optical Physics Division

October 11, 1966

[redacted]

NAVAL RESEARCH LABORATORY
Washington, D.C.

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Daylight Detection Distances of Letters and Hidden Stripes on Targets Observed at Near-Ultraviolet Wavelengths Through a Viewing Device

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Abstract [redacted]: Ten different lettered and striped targets illuminated by daylight were observed by eye with the aid of a viewing device which was sensitive at only near-ultraviolet wavelengths. Each of the 6×8-in. targets contained either (a) 4- or 6-in. letters, or (b) 1-, 2-, 3-, or 4-in.-wide horizontal stripes. Letters were either black on light backgrounds or vice versa, and stripes were brushed onto white backgrounds with a lacquer which was visibly transparent, but opaque at ultraviolet wavelengths. Eight of the targets contained a white cardboard which was a good near-ultraviolet reflector, and the other two target backgrounds were cut from a white and a silvery retroreflecting material.

Distances were measured out to the point where letters and stripes on individual targets ceased to be detected on a sunny day and on a variably overcast day. Stripes were detected out to distances of about 900 to 1200 ft, depending upon stripe width, whereas 4- and 6-in. letters were detected out to only about 300 to 450 ft. The above distances were measured when a special objective lens was mounted in the viewing device to provide a magnification of 7×. Letters were read through a Navy 7×50 binocular out to 1000 to 1100 ft. Target luminances were measured during all observations; the lighter areas ranged in value from 1000 to 6300 foot-lamberts.

In general, and not surprisingly, the larger letters and wider stripes were detected out to slightly greater distances. Also, targets in which the contrast between light and dark areas was greatest were detected out to the greatest distances. Black letters on white backgrounds were seen about as well as white letters on black backgrounds. To a small extent, the presence of both letters and stripes on the same target caused difficulty in detecting either feature independently.

INTRODUCTION

One proposed scheme for aiding in the solution of a current Navy problem requires that certain features of targets be invisible when viewed under normal conditions of illumination, but observable when viewed only at near-ultraviolet wavelengths. One means of producing these hidden target features is to coat appropriate areas of the surface of a highly reflecting material with an ultraviolet-screening lacquer. The surface must be a good reflector at both visible and near-ultraviolet wavelengths, and the coating of screening lacquer must be transparent at visible wavelengths and opaque at near-ultraviolet wavelengths. When a coated area is viewed under normal conditions, the bright underlying surface can be seen through it, but when viewed at near-ultraviolet wavelengths, the coated area appears dark. Since both the coated area and surrounding target surface appear bright at visible wavelengths, the coating cannot be seen readily; however, when a coated target is viewed at near-ultraviolet wavelengths, the coated area can be seen clearly because of the good contrast between its dark surface and the surrounding bright surface.

Some hasty, out-of-doors, daylight observations made through special viewing devices at near-ultraviolet wavelengths had given an indication of the distances out to which certain target features such as letters and hidden stripes could be detected. However, it was of interest to know with more certainty the distances out to which the target features could be detected under typical daylight conditions which were measured and recorded. Therefore, a set of more controlled

NRL Problem N03-02; Project RF 006-05-41-4401. This is an interim report on one task worked on under this problem; a summary report on the entire task is in preparation. Manuscript submitted August 2, 1966.

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observations which are reported herein was made.

TARGETS

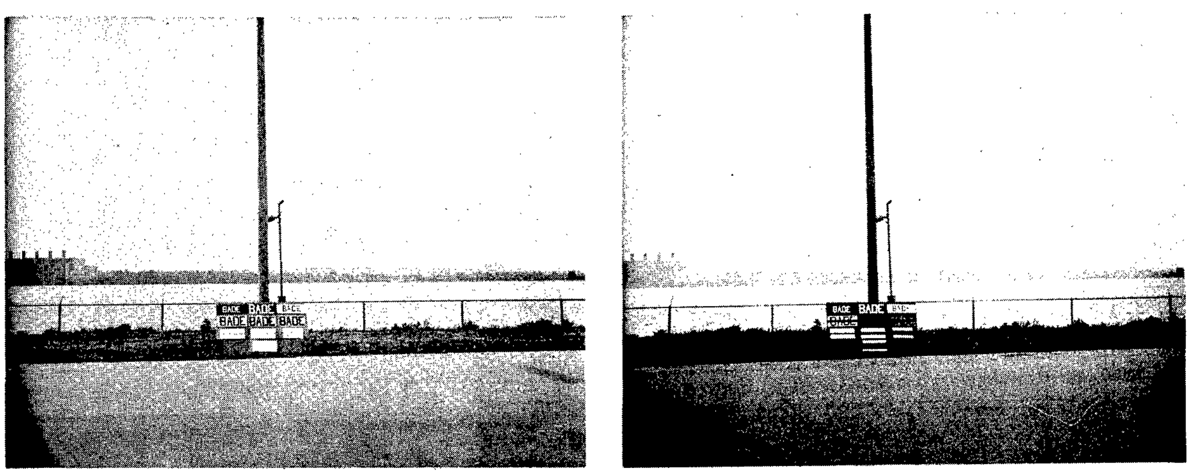
Ten different lettered and striped targets as shown in Fig. 1 were prepared. The target picture labeled "visible photograph" in Fig. 1 was reproduced from a photograph taken at visible wavelengths; the one labeled "ultraviolet photograph" was reproduced from a photograph taken at only near-ultraviolet wavelengths. To obtain the latter photograph a near-ultraviolet-transmitting and visible-absorbing filter (Corning color specification number 7-60) was placed in front of the camera lens. Both photographs were taken at a distance of 40 ft from the targets on an overcast day (no direct sunlight) at about 1400 in the afternoon with a Graflex Speed-Graphic camera. Type 52 (400 speed), 4×5-in. Polaroid film was used, and a 125-mm focal length, *f*/6 quartz lens was mounted in the camera. Lens speeds for the photographs taken at visible and near-ultraviolet wavelengths were *f*/45 and *f*/22, respectively, and shutter times were 1/125 and 1/25 sec, respectively.

Only stripes were intended to be of a hidden nature; letters could be seen clearly when viewed normally by eye. No special precautions were taken during target preparations to ensure that the stripes be completely hidden because this was not thought to be essential to the successful observations of target features; thus, the stripes can be seen in the visible target photograph in Fig. 1. Stripe coatings are discussed later in more detail.

Targets were made to produce maximum contrasts in their observed features so that they could be seen to the best advantage. Block-type letters (BADE), which were glued to target base materials, were either black on light backgrounds or vice versa. Letters were cut to recommended proportions for maximum readability: the width was 60 percent of the height, and the stroke was 15 percent of the height.* Overall target size was about 6×18 in. Some characteristics of important parts of each target are described briefly in Table 1. In Fig. 1 the upper left target is number 1; the others are numbered successively from left-to-right starting on the top row.

In target numbers 1 through 4 and 7 through 10, the white letters or backgrounds, as the case may be, were cut from sheets of Bainbridge Studio Bristol cardboard. This cardboard is highly reflective at visible wavelengths and is a better reflector than many other materials tested at near-ultraviolet wavelengths. The base material of target number 5 was a commercial white retroreflecting material, and the base of target number

*"IES Lighting Handbook," 3rd ed., p. 16-10, New York: Illuminating Engineering Society, 1962.



VISIBLE ULTRAVIOLET

Fig. 1 — Targets photographed at visible wavelengths and at near-ultraviolet wavelengths

[redacted]

Table 1
Description of Targets, Including Base Materials, Letters, and Ultraviolet-Screening Coats

Target Number	Base Material	Letters		Horizontal-Stripe Width of Ultraviolet-Screening Coat (in.)
		Height (in.)	Color	
1	Black cardboard	4	white	None
2	Black cardboard	6	white	None
3	White Bristol cardboard	4	black	None
4	White Bristol cardboard	6	black	2
5	White retroreflecting	6	black	2
6	Silvery retroreflecting	6	black	2
7	White Bristol cardboard	None		1
8	White Bristol cardboard	None		2
9	White Bristol cardboard	None		3
10	White Bristol cardboard	None		4

6 was a similar silvery retroreflecting material. Black letters were cut from commercial black paper, and black backgrounds were cut from available cardboard.

Except for the retroreflecting base materials, all white and black materials had mat surfaces, and therefore, they reflected light diffusely. One of the curves in Fig. 2 shows the total (diffuse plus specular) spectral reflectances of the white Bristol cardboard compared with the reflectances of a white magnesium oxide reference. Reflectances were measured using a Beckman DK-1 spectrophotometer. Similar reflectance measurements for the retroreflecting materials could not be made accurately with this instrument because of the retrodirectivity of the reflected light. However, even though the reflectance values were incorrect, the reflectance curves which were obtained for both white and silvery retroreflecting materials sloped sharply downward toward zero percent at wavelengths below approximately 400 nanometers (nm), or 4000Å. This sharp decline indicated the nature of the poor ultraviolet reflectances of both retroreflecting materials. All black surfaces in the targets had reflectances of less than 5 percent at both visible and ultraviolet wavelengths.

Retroreflecting materials were used as target bases because several preliminary observations made in darkness had shown that they appeared brighter than the cardboard when both types of materials were viewed through a viewing device at near-ultraviolet wavelengths and were illuminated properly by a light source close to the observer. Thus, the first indications, based on these observations, were that the retroreflecting materials might be superior base materials for targets viewed at night under searchlight illumination because of their high retrodirective reflectances.

The final step in preparing target numbers 4 through 10 was to make a horizontal stripe on the surface of each target using an ultraviolet-screening lacquer. Two coats of the lacquer, which is transparent at visible wavelengths and opaque at ultraviolet wavelengths, were brushed onto the target surfaces in the form stated in Table 1. The lacquer was specially formulated and prepared by members of the Chemistry Division at the Naval Research Laboratory and was designated AUS-1A. Figure 2 shows a curve for the total spectral reflectances of the ultraviolet-screening coat on the white Bristol cardboard of target number 4. The target stripes made with the screening lacquer were seen to be very dark when viewed at near-ultraviolet wavelengths, as shown in the ultraviolet photograph in Fig. 1. Stripes could also be seen when viewed at visible wavelengths, as shown in the visible photograph in Fig. 1, but this was because the surfaces of the stripe coatings

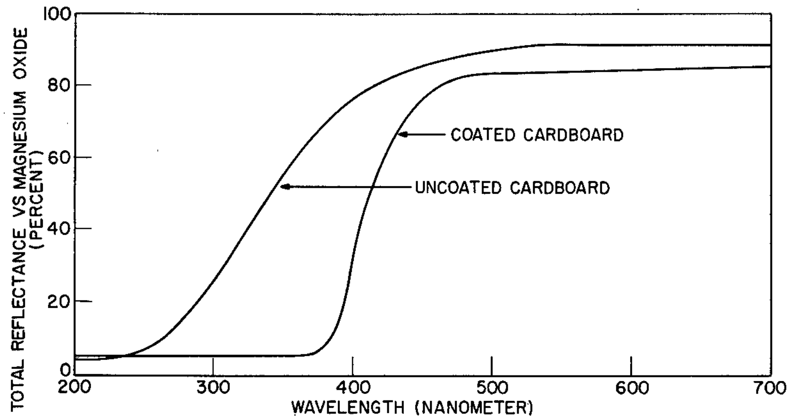


Fig. 2 — Total spectral reflectances of white Bainbridge Studio Bristol cardboard both uncoated and coated with AUS-1A ultraviolet-screening lacquer

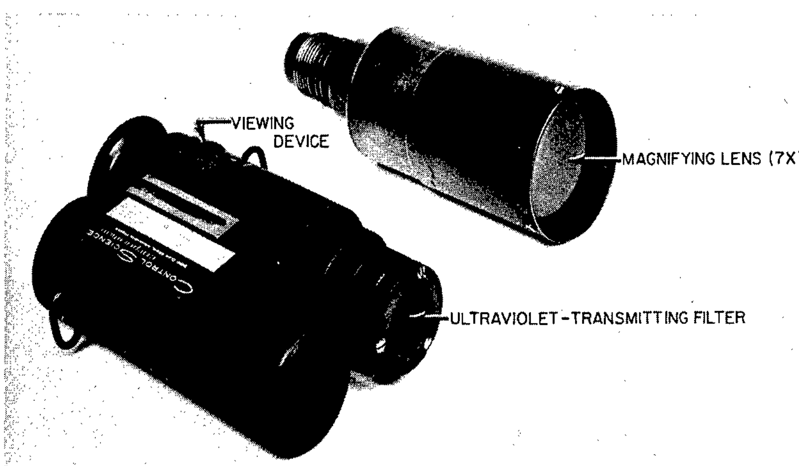


Fig. 3 — Hand-held viewing device showing near-ultraviolet-transmitting, visible-absorbing filter mounted in front of regular objective lens. Magnifying lens mount can be substituted for regular objective lens mount.

were not mat, as was the white cardboard surface, and because the ultraviolet-screening lacquer made the stripes appear slightly yellowish. By taking proper precautions, it has been demonstrated that ultraviolet-screening coats on surfaces can be made to be invisible, even on very close inspection.

VIEWING DEVICE

Targets were viewed through a near-ultraviolet-sensitive device which converted daylight ultraviolet radiation reflected from target surfaces into visible images of the targets. The viewing device (Fig. 3) was a hand-held, battery-powered, type MA-64 Metascope which was provided with a substitute RCA 7404 image-converter tube, a near-ultraviolet-transmitting and visible-absorbing filter, and either of two different objective lenses. The 7404 image tube, which has a photosensitive surface with an S-21 spectral response, is sensitive to radiation throughout the visible spectral region and at ultraviolet wavelengths down to 200 nm (Fig. 4). The ultraviolet-transmitting filter, Corning color specification number 7-60, was mounted in front of the Metascope to limit the

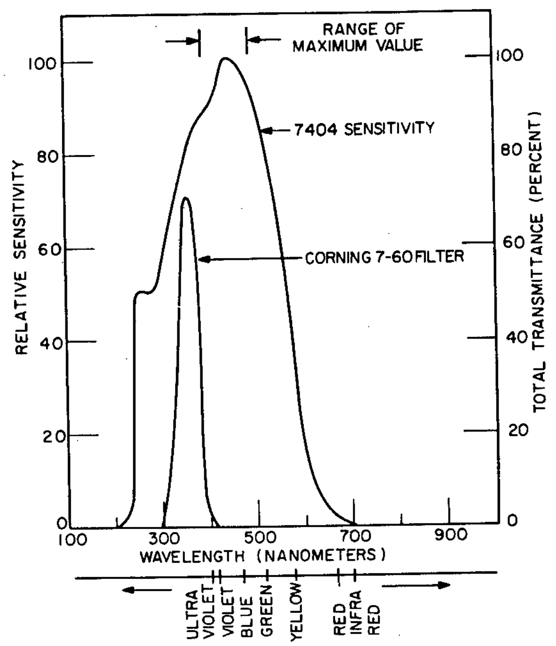


Fig. 4 — Relative spectral sensitivities of a 7404 image-converter tube photosensitive surface and total spectral transmittances of a Corning 7-60 filter used in the viewing device of Fig. 3.

radiation incident on the image tube photosensitive surface to the wavelength region below 400 nm. Spectral transmittances of the filter are shown in Fig. 4. Observations were made using both the regular objective lens of the Metascope and a special quartz magnifying lens (Fig. 3); the former lens magnified the apparent sizes of objects by 1.2 and the latter magnified them by 7.

OBSERVATIONS

The ten targets were observed on both a sunny day and a day when a slight and variable overcast prevailed (March 7 and 8, 1966). Each target was hung vertically, in turn, on a large plywood board facing in the general direction of the sun so that sunlight could illuminate the targets directly. Each target was viewed in a direction normal to its surface through the viewing device with either the regular objective lens or magnifying lens mounted in place; also, each target was viewed through a Navy 7×50 binocular. Luminances of small areas on both black and white surfaces of each target were measured with a Pritchard photometer placed close to the line of sight between the observers and each target.

The main purpose for the observations was to measure the distances out to which two different features of the targets could be detected through the viewing device. In one case, the observer tried to ascertain the presence of the letters BADE in the target; it was not necessary to read each letter, but only to establish with certainty that there were in fact four letters in the target. The other feature to be detected was the horizontal stripe of ultraviolet-screening coat on certain targets. Maximum distances for letter detection were measured for target numbers 1 through 6, and distances for stripe detection were measured for target numbers 4 through 10. Each of three different targets (numbers 4, 5, and 6) contained both letters and a stripe; each of these targets was observed twice, once for the letters and once for the stripe.

Results of the measurements are given in Tables 2 and 3 for the sunny and the overcast day, respectively; both tables list the observations chronologically. On the sunny day, observations were started with target number 1 in the morning at 0940 when the luminance of the white Bristol cardboard surface was 2900 ft-L. By the time the last observation was made at 1130, the surface luminance of target number 4, which was also white cardboard, was 6300 ft-L. Since there were no clouds in the sky to pass into the path of the direct sunlight incident on the targets, the increase in target surface luminances was generally steady and uninterrupted as the sun rose higher in the sky. Exceptions were found for luminances measured on the surfaces of the retroreflecting materials (target numbers 5 and 6), in which cases luminances were less than what would have been expected for the luminances of the white Bristol cardboard surface. Luminances of black surfaces were measured to be close to 20, 17, and 13 times less than those of the white cardboard and white and silvery retroreflecting materials, respectively.

Table 2 shows that the range of maximum distances measured on a sunny day to detect various features of the targets extended from 60 to 1225 ft, depending mainly upon the viewing device objective lens, the type of target feature which was viewed, and the reflectances of the target materials. On the average, target features

TABLE 2
Maximum Letter and Stripe Detection Distances Measured to Targets on a Sunny Day

Target Feature Detected	Target Number	Time of Day	Approx. Luminance of Light Target Surface (ft-L)	Detection Distance (ft)		
				Regular Lens	Viewing Device Magnifying Lens	Binocular
4-in. white letters	1	0940	2900	135	300	970
6-in. white letters	2	0950	3400	170	465	1105
4-in. black letters	3	0955	3600	140	375	1025
6-in. black letters	4	1010	3900	150	405	1040
6-in. black letters	5	1040	4400	60	105	1070
6-in. black letters	6	1045	3400	110	265	1060
1-in. stripe	7	1050	5100	310	880	
2-in. stripe	8	1055	5200	400	1100	
3-in. stripe	9	1100	5300	415	1225	
4-in. stripe	10	1110	5700	465	1150	
2-in. stripe	6	1120	3700	230	550	
2-in. stripe	5	1125	5100	150	310	
2-in. stripe	4	1130	6300	350	1045	

were detected at distances 2.5 times greater when the magnifying lens was mounted in the viewing device than when the regular lens was in place. Stripe detection distances were much greater than detection distances for both 4- and 6-in. letters. Stripes which were 2, 3, and 4 in. wide were seen through the viewing device with the magnifying lens in place out to distances (1100 to 1200 ft) as far or farther than the distances at which 6-in. letters could be read through a Navy 7×50 binocular.

The degree of contrast between white and black portions of targets as seen through the viewing device affected both letter and stripe detection distances. Since the viewing device was sensitive to near-ultraviolet radiation alone, only effective ultraviolet contrasts were seen through it; these contrasts were not related systematically to the visible contrasts. Target base materials, listed respectively in the order of good to poor ultraviolet reflectors, are Bristol cardboard and silvery and white retroreflecting materials. When targets of these base materials were viewed through the viewing device, the good ultraviolet reflector (Bristol cardboard) appeared bright and afforded good contrast with dark portions of the target; the poor ultraviolet reflector (white retroreflecting material) appeared less bright and afforded poor contrast with dark portions. The effect of contrast differences shows up in the measured distances recorded in Table 2 for target numbers 4, 6, and 5, which had base materials of Bristol cardboard and silvery and white retroreflecting materials, respectively. Six-inch black letters on target numbers 4, 6, and 5 were detected through the viewing device with the magnifying lens in place out to distances of 405, 265, and 105 ft, respectively. Note that the greatest distance was measured for the best ultraviolet-reflecting base material and the least distance for the poorest ultraviolet reflector. With the regular lens mounted in the viewing device, the magnitudes of the maximum detection distances (150, 110, and 60 ft) were again in the same order as the magnitudes of the effective ultraviolet reflectances of the target base materials. Similarly, the magnitudes of stripe detection distances were found to be in the same order as for letter detection distances stated above; maximum stripe detection distances for target numbers 4, 6, and 5 were 1045, 550, and

310 ft, respectively, with the magnifying lens, and 350, 230, and 150 ft, respectively, with the regular lens.

Stripe widths were found to affect the maximum distances out to which stripes could be detected. Target numbers 7, 8, 9, and 10 were prepared with 1-, 2-, 3-, and 4-in.-wide horizontal stripes, respectively, through the middle of a 6-in.-wide piece of white Bristol cardboard (see ultraviolet photograph in Fig. 1). Maximum stripe detection distances measured for these targets and recorded in Table 2 were generally greater for wider stripes. The greatest increase in detection distance occurred when the stripe width was increased from 1 to 2 in. In one case (viewing device with magnifying lens), the 3-in. stripe was detected at a greater distance (1225 ft) than the 4-in. stripe (1150 ft). A factor to consider when comparing the distances for these two stripe widths is that a 4-in. dark stripe on a 6-in.-wide target base allows only 1 in. of bright surface to show along each of the upper and lower target edges, whereas a 3-in. stripe allows 1-1/2 in. of bright surface to show along each edge.

During the course of the observations, observers commented on the fact that the presence of both letters and stripes on the same target increased the difficulty of detecting either feature independently. These observer comments are supported by the trends of the detection distance magnitudes noted for certain targets. For example, stripe detection distances for target number 4 were less than those for target number 8 (Table 2) although both targets had 2-in.-wide stripes on the same type of base material (white Bristol cardboard); however, target number 4 had 6-in. black letters and target number 8 had no letters. Target number 4 was seen at the lesser distance even though its white surface luminance was higher (6300 ft-L) than that (5200 ft-L) for target number 8. The stripe on the lettered target was detected out to 350 ft, and the stripe on the unlettered target was detected farther out to 400 ft when they were observed through the viewing device with the regular lens mounted in place; when the magnifying lens was placed on the viewing device, the maximum distances measured to lettered and unlettered targets were 1045 and 1100 ft, respectively.

Effects of differences in letter height on detection distances were noted during the observations. As would be expected, 6-in. letters were always observed at greater distances than 4-in. letters, although the distance improvements were not as great as would be expected in all cases. Poor distance improvements may be explained partly by the fact that one of the targets with 6-in. letters (number 4) had a 2-in.-wide stripe on its surface; as mentioned above, this stripe did increase the difficulty of detecting target letters. Another partial explanation for poor distance improvements which observers noted was the lack of an upper and lower border on targets with 6-in. letters. Since targets were only 6 in. wide, the 6-in. letters extended to the top and bottom edges of each target, a condition which did not allow area for a border along the tops and bottoms of these targets. On the other hand, targets with 4-in. letters had a 1-in. border at both top and bottom. This border was apparently an aid to detection because of the contrast it provided.

All of the foregoing discussions about target features and detection distances are based upon observations made on a sunny day. The effects of target feature differences on detection distances can be ascertained more reliably on a sunny day when target brightnesses change slowly and gradually than on a variably overcast day such as occurred when the data in Table 3 were gathered. Luminances of white target surfaces recorded in Table 3 changed quickly by factors greater than 2 at times from one observation to the next. In general, however, the data taken on the overcast day agreed with those taken on the sunny day, but most of the distances measured on the overcast day were less.

CONCLUSIONS

Daylight observations made at near-ultraviolet wavelengths of targets described in this report clearly show that, in general, stripes were detected out to much greater distances than letters. This conclusion applies to 1-, 2-, 3-, and 4-in.-wide horizontal stripes made with ultraviolet-screening coats on the surfaces of 6-in.-wide pieces of white cardboard, which was a good near-ultraviolet

TABLE 3
Maximum Letter and Stripe Detection Distances Measured to Targets on a Variably Overcast Day

Target Feature Detected	Target Number	Time of Day	Approx. Luminance of Light Target Surface (ft-L)	Detection Distance (ft)		
				Regular Lens	Viewing Device Magnifying Lens	Binocular
4-in. white letters	1	1100	1700	95	290	995
6-in. white letters	2	1120	1000	135	350	1275
4-in. black letters	3	1130	1000	110	260	1100
6-in. black letters	4	1140	1900	125	310	1310
2-in. stripe	4	1150	2000	345	725	
6-in. black letters	5	1335	4400	35	75	1090
2-in. stripe	5	1340	4300	105	345	
6-in. black letters	6	1350	2700	100	175	1035
2-in. stripe	6	1400	2700	230	465	
2-in. stripe	8	1408	2600	350	1015	
3-in. stripe	9	1410	3500	390	1015	
4-in. stripe	10	1412	1900	400	960	
1-in. stripe	7	1415	2100	265	735	

reflector. The letters were black and were either 4 or 6 in. high on the same type of cardboard. As would be expected, 6-in. letters were detected at greater distances than 4-in. letters, and wide stripes were detected at greater distances than narrow stripes. It was found that stripes could be detected out to about the same distances (1000 to 1200 ft) at which letters could be read through a Navy 7×50 binocular on a sunny day. An objective lens which produced a magnification of 7 in the viewing device was required to attain these greater stripe detection distances.

The observations also showed some effects of other factors on detection distances. In viewing situations where the contrasts between bright and dark portions of targets were greater, maximum detection distances were found to be greater. Contrasts were greater on a sunny day than on an overcast day, and they were also greater for targets in which light parts of the surfaces were good near-ultraviolet reflecting materials. Finally, it was found that, to a small extent, the presence of both letters and stripes on the same target caused observers difficulty in detecting either feature independently.

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