Air Sea Rescue bulletin

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THIS MONTH'S COVER . . . hardly requires description, so well does it portray—in the faces of these three British merchant seamen—the desperate ordeal of their fight for survival. Victims of a torpedo attack on their ship in the North Atlantic, they are here shown being rescued by a Coast Guard combat cutter. *Coast Guard Photo.*

It is the policy of the Bulletin to keep its readers informed of the development progress of important items of search and rescue equipment, regardless of whether or not the item has been previously discussed in its pages. The Bulletin, in 1944, carried two articles on signaling mirrors. However, believing our readers would be interested in a complete, authoritative discussion of this important piece of equipment, we are pleased to offer this timely article by Mr. Hunter of the National Bureau of Standards. Ed.

A pocket-size mirror will reflect flashes of sunlight readily visible to an observer 10 or 20 miles away on a clear day. Because such a small inexpensive device will produce signals visible at considerable distances, all branches of the United States armed services now equip their lifeboats, rafts and floats with heliographic signaling mirrors. These are pocket-size, corrosion-resistant, reasonably flat mirrors of specially strengthened glass or shiny metal which possess some means for aiming reflected sunlight. Three methods for aiming reflected sunlight have proved worthy of extensive use: foresight, rearsight, and retroreflector. A foresight type of mirror has been widely used by the British in their survival equipment. The majority of mirrors produced for American equipment have been of the rearsight type. Manufacture of mirrors of the retroreflector type unfortunately did not start till the middle of 1944, for this is without question the best of the three types. With a retroreflector-type mirror, a signaler merely has to look through a sighting window in the mirror, find a red spot which appears in space in front of the mirror, and then twist the mirror to put this red spot on the target.

I. INTRODUCTION

A pocket-size mirror will reflect flashes of sunlight readily visible to an observer 10 or 20 miles away on a clear day. Because such a small inexpensive device will thus produce signals visible at considerable distances, all branches of the United States armed services now equip their lifeboats, rafts and floats with heliographic signaling mirrors.

Surveyors, mountain climbers, and explorers have known for many years of the use of mirrors for signaling. However, mirrors were not included with American survival equipment until the Rickenbacker search and rescue early in the war focused attention on the need for a simple signaling device with which survivors in a raft could attract the attention of passing craft. A number of reports were published, at about the time of the Rickenbacker search, of survivors from ship sinkings and downed aircraft who had successfully improvised methods of reflecting flashes of sunlight toward searchers from tin-can bottoms or other shiny objects. One man, who is known to have urged the development of a signaling mirror, was a former Pan-American Airways pilot who once located the wreckage of an airplane in the Gulf of Mexico only because survivors on the wreckage had been able to direct mirror flashes of sunlight at him.

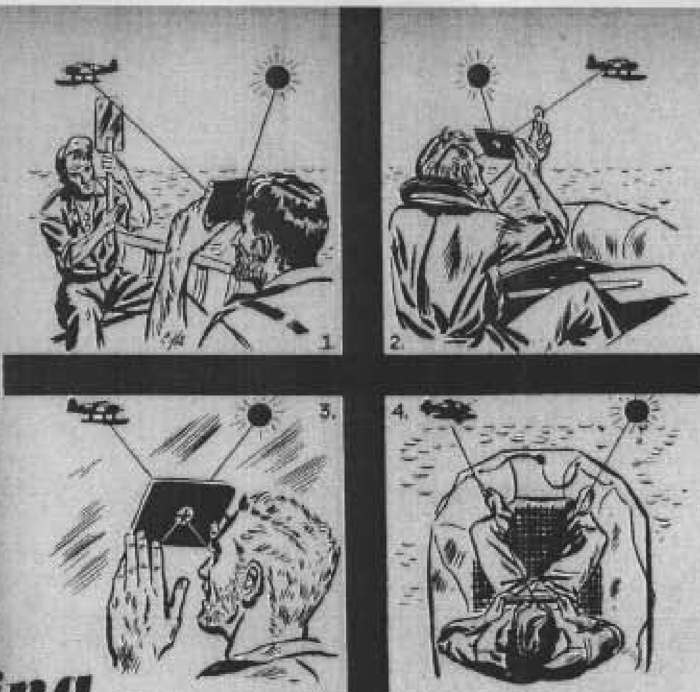
To a passing observer several miles away, signals from a small mirror appear as bright, irregularly spaced flashes of light coming from a point in the distance which is usually near the horizon. The brightness which the flashes appear to have is determined by the size, flatness, and reflectance of the mirror, the distance between rescuer and survivor, and the clearness of the atmosphere. The frequency with which flashes reach the observer is determined by the skill of the survivor and the suitability of the mechanism for aiming mirror-reflected sunlight.

In September 1942 representatives of the United States Coast Guard, the Office of Strategic Services, and the National Inventors Council came to the National Bureau of Standards and asked for assistance in

heliographic signali

By Richard S. Hunter, National Bureau of Standards

Rear side of aluminized, tempered-glass signaling mirror manufactured by the General Electric Co. and intended for rearsight aiming (Courtesy of General Electric Co.)



ling mirrors

Four methods of aiming mirror flashes of sunlight: (1) improvised foresight, (2) foresight (British mirror), (3) rearsight (General Electric mirror) and (4) retroreflector.

designing a practical signaling mirror which could be packed with life rafts, lifeboats, and other survival equipment. Three questions were raised: (1) What are the best mirror materials from the standpoint of shininess, ability to resist corrosion, and resistance to breakage? (2) What size and flatness must a mirror possess to produce flashes of sunlight bright enough to attract the attention of an observer in any passing aircraft or boat likely to be seen by a survivor? (3) What simple and effective means can survivors employ to aim mirror flashes of sunlight toward a passing craft?

The first two questions were readily answered by information already available plus the results of a few trials and experiments. To the last question, however, there was no ready answer. A few trials soon showed that mere guesswork in handling a mirror without some accurate scheme for aiming flashes would not work. If one fails by only half a degree to face a mirror half way between the sun and the target, the mirror signals will not reach the target. Within a few days of the receipt of the request for assistance, however, L. L. Young, then of the Bureau staff, had devised the rearsight method for aiming mirror flashes and had shown that it was accurate and could be readily provided for in the manufacture of small mirrors.

Suggestions for other methods of aiming mirror signals came from other sources. Unquestionably the best of these is the retroreflector method which was submitted by its inventor, C. H. Learned, of California, to the National Inventors Council, several months after Young had suggested the rearsight method.

II. MIRROR MATERIALS

The materials from which good, shiny mirrors can be made are all familiar, excepting perhaps for mirrorized transparent plastic sheet which has appeared only recently. Signaling mirrors of evaporated aluminum on glass and of precipitated silver on glass have been widely manufactured in spite of the objectionable brittleness of glass. With some mirrors, this objectionable feature has been partially overcome by prior heat treatment of the glass to increase resistance to breakage. With others, the glass has been mounted in a cushioning metal and rubber frame. Coatings of lacquer or paint are, of course, applied to the metal films on these mirrors to prevent corrosion.

Signaling mirrors have also been made of chromium-plated brass and steel. To obtain satisfactory resistance to corrosion from mirrors of this type, the plating must be well applied, or it will not prevent corrosion. One survival account brought to the writer's attention demonstrates the importance of corrosion resistance. A flyer forced down in the South Pacific had been adrift 2 weeks when he sighted a patrol plane. Although the sun was shining at this time and the flyer knew how to operate his chromium-plated signaling mirror, he was unable to signal because of the corrosion of the mirror. Only the sharp eyes of the pilot of the patrol plane brought about his rescue.

Stainless steel has good resistance to salt-spray corrosion. Although the British made a good signaling mirror of polished stainless steel, it is believed that no American agency tried using this material, in part because it was in short supply during the war, and in because it did not readily lend itself to the types of construction being tried. Recently, the development of a stainless steel Scotchlite type signaling mirror has been undertaken. Having both resistance to breakage and resistance to corrosion, stainless steel would seem to be an ideal material for signaling mirrors.

The possibilities of mirrorized transparent plastic are not known. Good plastice mirrors can apparently now be made by both evaporation and chemical precipitation of metal films on transparent sheet. If otherwise practical, plastic signaling mirrors would combine the advantages of light weight with freedom from brittleness. The plastic mirrors examined to date, however, have all tended to warp in warm humid atmospheres till they failed to comply with the experimentally established requirements for mirror flatness which are described below. Until this tendency to warp can be overcome, as it may be in some of the recently developed plastic materials, signaling mirrors of plastic will continue to prove unacceptable.

Mirror reflectance, which might at first seem an important consideration in the choice of a mirror material, is actually of secondary importance. Of the materials mentioned above, a clean mirror of silver on glass will reflect more than 90 percent of the light which strikes it at 45°, a mirror of aluminum on glass will reflect about 85 percent, chromium-plated brass or steel 60 to 65 percent, and polished stainless steel, 50 to 65 percent. Although the differences in brightness between flashes from like-sized mirrors of the best and the poorest of these materials could be perceived if the flashes were viewed simultaneously and side by side, the flashes would be of so nearly the same brightness that there would be little difference in their power to attract the attention of an observer. Slight bending or warping of a mirror causes a much more serious loss of signal brightness.

III. MIRROR DIMENSIONS AND FLATNESS

Recommended sizes and flatnesses for signaling mirrors were obtained from the results of experiments conducted over an 8-mile range across the city of Washington. Because it is unlikely that a survivor will see any rescue craft more than 8 miles away, it was felt that mirrors giving effective signals over this range should be suitable as items of survival equipment.

Flashes of sunlight from a nonflat, 2-inch square, stainless-steel signaling mirror were seen across this 8-mile range. The flashes were not bright, however. On the other hand, flashes of sunlight from every mirror which was 3 by 4 inches in size or larger, and suitably flat, were quite bright.

It may thus be said that a mirror which readily fits into one's pocket is large enough to be an effective signaling mirror. In American survival equipment, mirrors about 3 by 4 inches in size are usually found in lifevests and small packs where space and weight are at a premium. Mirrors 4 by 5 inches or 5 by 7 inches are found in lifeboats, in large packs, and where space and weight are not so vital.

Mirrors of these sizes must be nearly flat to be suitable. A perfectly flat signaling mirror will reflect a beam of sunlight into space which has the form of a cone 0.5° in diameter measured from the mirror. This is because the sun is 0.5° in diameter when observed from the earth. If a mirror is not flat, the spread of the beam of reflected sunlight will be greater and the flashes of reflected sunlight will be correspondingly dimmer. In the experiments over the 8-mile range it was found that slight warpage improved a signaling mirror because the additional spread of the reflected beam caused suitably bright flashes of sunlight to reach the observer with greater frequency than from a perfectly flat mirror. A limit was found to the amount of warpage which could occur before the loss of brightness of the reflected flashes became serious.

The amount of warpage was measured on a mirror-planarity meter designed by M. K. Laufer of the National Bureau of Standards. With this instrument the beams of light reflected from different parts of a mirror under test were measured for their angular deviations from the direction of reflection by a flat mirror. The signals from a 4- by 5-inch mirror began to show serious loss of brightness when the average deviation of the beams from the direction of reflection by a flat mirror was about 1°. With a 3- by 4-inch mirror this figure was about 0.6°.

The sagittal distance of a 4- by 5-inch concave or convex mirror with maximum permissible curvature is about 0.020 inch, that of a 3- by 4-inch mirror with maximum permissible curvature is about 0.010 inch. Although care is necessary to avoid warping the strengthened-glass mirrors during heat treatment and the metal mirrors during mechanical finishing, the required planarity is not difficult to obtain.

IV. FORESIGHT TYPE MIRRORS

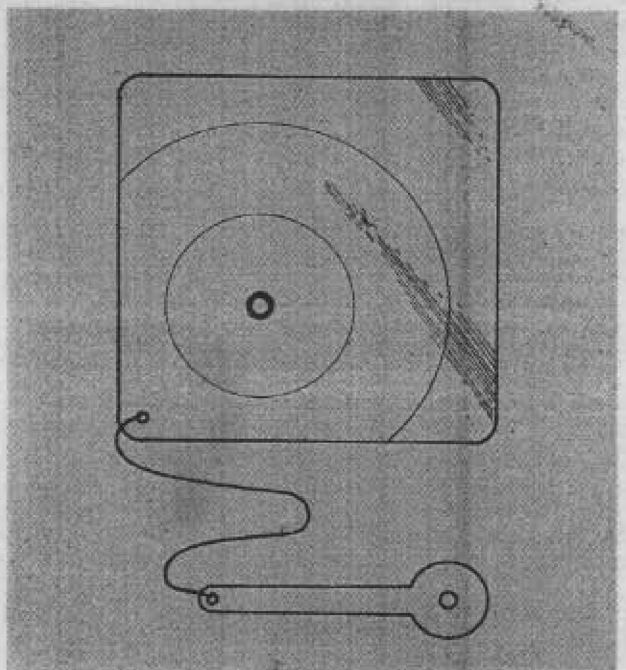
Four different methods for aiming mirror-reflected beams of sunlight are illustrated in figure 1 in the order of their effectiveness. The methods shown in squares 1 and 2 should both be called foresight methods of aiming a mirror because in each sunlight is reflected from the mirror onto a nearby object in the signaler's line of sight. Square 1 illustrates an improvised method of foresight aiming and square 2 shows the operation of a foresight signaling mirror built for the purpose.

From the accounts of survivors who have successfully improvised mirror methods of signaling, it appears that when prepared signaling mirrors are lacking, an improvised method of operation similar to that shown in square 1 is most likely to be successful. There is a question whether the particular two-man method of operation shown should be used in a boat craft on rough water. The motion of the men makes it difficult to keep the foresight near the signaler's line of sight to the target. The signaler may be more successful if he uses his own hand as a foresight.

On land, where the signaler is not in continuous motion with respect to his surroundings, it is easier to keep a foresight in line with a target. Sometimes it is convenient to use a part of a bush or tree as a foresight. Flashes of sunlight from a toilet mirror, a tin-can bottom, or a plain piece of glass can be aimed quite easily and accurately by one on firm ground. For successs, the alinement of the signaler's eye, the mirror, the foresight, and the target must be made carefully.

It is quite usual to find an individual practicing the

British 4 by 4 inch stainless-steel signaling mirror with white-painted metal key.



foresight method of signaling who thinks he is directing flashes to a distant target and yet does not hold his mirror close to his eyes. Although one sees reflected light striking the foresight, and the foresight is properly in line with the target, signals will not be directed toward the target unless the mirror-reflected beam of sunlight and one's line of vision start from essentially the same location. Failure of the signaler to hold his mirror close to his eyes is a very common error of the improvised foresight method.

With mirrors manufactured for foresight aiming, correct alinement is assured by sighting through holes. Foresight-type pocket signaling mirrors of practically the same design have been proposed by C. H. Wilson of California and T. D. Robertson of Australia, and they have been procured and issued as survival equipment by the British armed services.

The British stainless-steel signaling mirror shown in figure 2 is 4 by 4 inches in size and $\frac{1}{16}$-inch thick. The key, attached by string to the mirror, is painted white. Rings concentric about the sighting hole have been scratched on the shiny face of the mirror. These enable the signaler to tell from the shadows of these rings on the white key which way he must turn the mirror to bring the shadow of the dark spot and sighting hole onto the center of the key. The problem confronting a signaler such as is shown in square 2 of figure 1 is to keep his line of sight through the mirror and keyhole aimed toward the target, and at the same time keep the shadow of the sighting hole centered on the keyhole.

V. REARSIGHT TYPE MIRRORS

The rearsight method of aiming a mirror-reflected beam of sunlight makes use of the small pencil of sunlight which comes through the sighting hole. There must be a rearward mirror surface surrounding the sighting hole in addition to the mirror surface facing forward. The pencil of sunlight which comes through the sighting hole is intercepted by some object behind the mirror, such as the signaler's face or hand, and is then observed by reflection in the rearward mirror surface. (See fig. 3 or square 3 of fig. 1.) It is the task of the signaler to turn the mirror so that the reflected image of the intercepted spot of light disappears from the rearward mirror surface into the sighting hole at the same time the line of sight through the hole is directed to the target. Aiming a mirror by the rearsight method is not a simple task.

The rearsight scheme for emergency signaling mirrors appears to have been first suggested by T. D. Robertson [3] in Australia. Robertson's suggestions were slow in reaching the United States, and both L. L. Young, formerly of the National Bureau of Standards, and W. M. Potter, of the General Electric Co., conceived the rearsight scheme independently while working on signaling-mirror possibilities late in 1942.

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[3] *See Australian patent 117,760 issued November 25, 1943, to Thomas Dunn Robertson for an improved mirror signaling device. According to this patent, Robertson's initial application was accepted January 12, 1940, but since the patent covers both the foresight and rearsight types of signaling mirror, it is not possible to say with certainty that the rearsight scheme for aiming signaling mirrors was suggested in 1940.*

The excellent rearsight mirror of Potter's design, including his original specification of tempered glass, was placed in production by C. F. Perkins of the General Electric Co. and widely distributed with American survival equipment. One type is shown in a rear-view photograph (Fig. 3).[4] The mirror is of evaporated aluminum on tempered glass which will not break when dropped from a height of 5 feet onto a hardwood floor. The sighting hole is in the shape of a cross so that the signaler has a somewhat wider field of view than a round hole would give. For a rearward mirror surface surrounding the sighting hole, the evaporated aluminum film of the mirror was coated with only a clear, tough lacquer. The rear of the mirror with its instructions and the circular reflecting area are shown in figure 3.

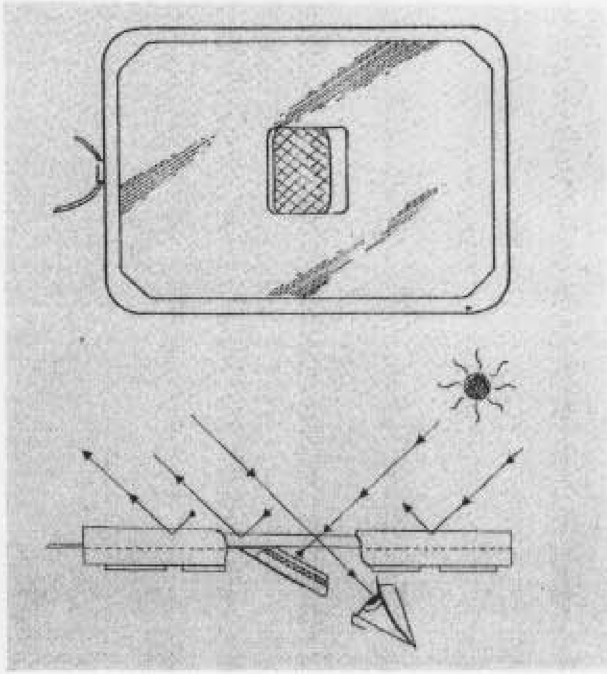
Rearsight signaling mirrors of sheet steel chromium-plated on both sides have been made. Although these mirrors do not possess the susceptibility to fracture of glass mirrors, the resistance of many of them to salt-spray corrosion is poor. In addition, many of them have been found to be seriously warped, either due to carelessness in manufacture or to the use of sheet metal too thin to resist bending in handling and shipping.

VI. RETROREFLECTOR-TYPE MIRRORS

The idea for the retroreflector type of signaling mirror was submitted to the National Inventors Council for use in the war effort by a Californian named C. H. Learned. He proposed that an aiming mechanism be made by fastening a retroreflector of one of the types widely used in night-visible traffic signs behind a glass of plastic window in a mirror. Whenever sunlight strikes the front of this mirror, that part which passes through the window strikes the retroreflector and starts to return toward the sun. Some of this beam of reversed sunlight is reflected to the rear by the two surfaces of the glass or plastic window. If these two surfaces are parallel to the surface of the mirror, it is easy to see that the direction taken by this rear-reflected beam (usually colored red by the retroreflector) will be exactly opposite to that taken by the main mirror-reflected forward beam. This is shown in the lower part of the drawing, figure 4, of the Signal Service Corp.'s model of emergency signaling mirror.

The rearward beam is seen as a red spot by the survivor who places his eye beside the retroreflector in the position shown. This red spot is actually an imperfectly formed image of the sun appearing in space in the direction in which the mirror is reflecting sunlight. In comparison with the foresight and rearsight types of signaling mirror, the retroreflector type of signaling mirror has three important advantages: (1) The method of aiming is not complex; the survivor merely holds his eye behind the mirror, observes the red spot appearing in space, and turns the mirror until this red spot appears to coincide with the target. (2) There is no difficult problem of focussing the eye because the red spot appears at a great distance in front of the mirror. With the other methods of aiming, it is necessary for the survivor to look repeatedly from nearby to a target in the distance and back again. (3) The survivor has a large field of view because the mirror window is fairly large and he can hold his eye immediately behind it.

Retroreflector-type mirror manufactured by the Signal Service Corp. Part of case is cut away to show directions of rays involved in signaling.



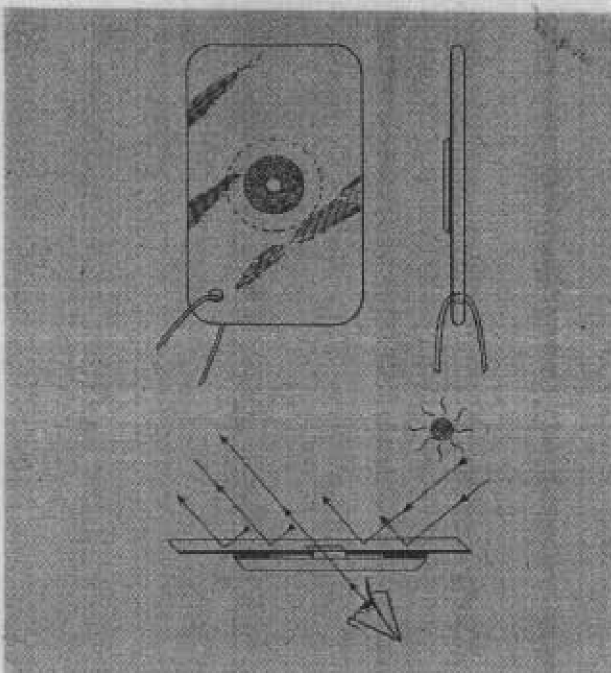
The Signal Service retroreflector-type signaling mirror shown in figure 4 uses an ordinary silver-backed glass mirror built into a cushioning frame and has, as an additional feature, retroreflectors which face rearward for possible use by a survivor in a night rescue. However, the signaling mirror has one disadvantage which it has been possible to eliminate in a recently designed retroreflector-type signaling mirror. The mirror shown in figure 4 must be rotated in its own plane till the retroreflector faces roughly toward the

[4] *See article entitled "Solar Searchlight," by W. M. Potter, General Electric Review 47, p. 7 in May 1944 issue.*

sun before the red spot can be seen by looking through the viewing window. The proper positions of reflector, sun and signaler's eye are indicated in figure 4 and in square 4 of figure 1.

A retroreflective material manufactured by the Minnesota Mining & Manufacturing Co. comes in the form of sheets to which small spherical glass beads have been affixed. Its brand name is Scotchlite. One form of this material is well suited for making retroreflector-type signaling mirrors. It can be cut into washers with sighting holes in the center and each washer can then be mounted behind a round window of glass or plastic in a mirror. When the retroreflector has this washer shape, it makes no difference how the mirror is turned in its own plane; the necessary rearward beam to form the red spot will always come back through the sighting hole. The Scotchlite-type of signaling mirror which the General Electric Co. has made with an aluminum-coated, tempered-glass mirror and disk-shaped protecting cover glass is shown in figure 5. This improved signaling mirror had not reached quantity production at the time the war ended.

Retroreflector-type mirror made with Scotchlite washer behind round window in tempered-glass mirror by the General Electric Co. Cross-section of aiming mechanism below shows directions of rays involved in signaling.



VII. COMPARATIVE TEST OF SIGNALING MIRRORS

To compare some of the above types of mirrors for effectiveness under simulated survival conditions, a series of tests was conducted in May 1944 at the United States Coast Guard Air Station, Elizabeth City, N. C. The mirrors compared were operated by the four methods illustrated in figure 1. Unfortunately the Scotchlite type of retroreflector mirror shown in figure 5 had not been developed at this time.

To operate the signaling mirrors, six subjects with no previous knowledge of these devices were chosen from among the machinists at the station and then divided into three two-man teams. The first trials were used to find how rapidly the proper methods for aiming mirror-reflected flashes of sunlight could be learned from the instructions and diagrams supplied. Between 2 and 3 minutes was the average period of time required by the teams to learn each of the four methods of aiming. There were thus no significant differences in the ease with which the various aiming techniques were learned.

On the following day, the subjects were taken in a radio-equipped cabin cruiser to an area in Albemarle Sound where the water was somewhat choppy and there a four-man rubber raft was tied to the stern of the anchored boat. Between 10:30 and noon a scouting plane repeatedly passed around the boat and raft at an elevation of about 500 feet. It always approached from the up-sun direction, circled 2 miles from the raft, and then left to go 6 miles up-sun before turning for the next run. The small scouting plane could be seen only when it was within about 4 miles of the boat. During each circuit, one team of men in the raft tried to signal with two of the four mirrors. One man signaled for 30 seconds with one mirror and then for 30 seconds with the other before relinquishing both to the other man in his team.

An observer in the scouting plane reported by radio the number of distinct flashes of sunlight which he saw during each 30-second period. A comparison of two mirrors was made during each run so that valid comparisons would be obtained even though changes in the subject's ability or the weather might change the rating scale during the course of observations. Fortunately the average rate at which flashes were received from any one mirror did not change markedly, either with changes of subjects, or with course of the experiment. Thus the results can be summarized

(*Continued on page 48*)

Heliographic Signaling Mirrors

(*Continued from page 29*)

by giving merely the average rate at which flashes of sunlight were received by the plane from each signaling mirror:

	Average number of flashes observed per minute
1. Improvised foresight aiming method	0.3
2. Stainless-steel foresight mirror	8
3. Tempered-glass, rearsight (G. E.) mirror	14
4. Retroreflector (Signal Service Corp.) mirror	35

From the results it is apparent that the retroreflector-type mirror performed most effectively, while the improvised foresight method was poorest. The stainless-steel foresight and General Electric rearsight mirrors were intermediate in effectiveness.

Though the retroreflector-type mirror definitely gave the best performance during signaling, it was not noticeably superior to other mirrors in the ease with which the subjects learned to use it properly. The chief trouble which the subjects encountered in learning to use the new mirror resulted from their failure to discover that it is necessary always to face the retroreflector roughly toward the sun before it produces a visible red spot for use in aiming. With the recently developed Scotchlite-type signaling mirror, this difficulty with aiming has been eliminated, so it is felt that the newest device is superior to anything that has heretofore been used for mirror signaling.

VIII. CONCLUSION

The heliographic signaling mirror is a small, inexpensive, yet effective signaling device; however, it has limitations. Naturally it will not work when the sun is behind clouds. In addition, it cannot be used to direct signals at angles too far from the sun. Each of the methods of aiming described above gets more difficult to use as the angle between the sun and target gets larger than 90°. The retroreflector type mirrors will not work at angles greater than about 135° because the retroreflective materials cease to function with light incident on them at more than 65° or 70° from normal. Even though flashes cannot be aimed in directions more than 135° from the sun, signals can nevertheless be directed to every part of the sky when the sun is more than 45° above the horizon, and they can be sent to all but a small segment of the sky when the sun is lower.

With retroreflector-type mirrors, there is a cone of directions immediately surrounding the sun into which signals cannot be aimed. The existence of this cone of directions is due to the necessity for lateral travel of the aiming beam within the mirror from the retroreflector where it starts to the sighting hole. (See figs. 4 and 5.) When sunlight strikes a mirror perpendicularly, there is no lateral travel of this beam. In practice, this cone of directions in which the aiming mechanism does not operate is from 20° to 30° in diameter with the sun as its center. However, it covers only a small fraction of the total area of the sky and the user of a signaling mirror can easily hold this area to a minimum by remembering to move his eye to the side of the sighting hole opposite the sun and nearest the target.

In spite of limitations, the new retroreflector-type signaling mirrors seems well worth placing on all American ships and overseas aircraft along with the other best items of survival equipment developed during the war. It may be expected that the new device will also find use by surveyors, mountain climbers and other persons engaged in outdoor activities. Forest Service officials have expressed interest in the mirror as a possible device to use in signaling between airplanes and crews on the ground.

To enlarge its possible usefulness and to improve it as an air-sea rescue device, a method has been developed to obtain red, yellow, and green signals from a signaling mirror which are readily distinguishable from each other and from the usual achromatic signals. To obtain each of these chromatic signals, a film of red, yellow, or green cellulose acetate film was held in front of the mirror. A hole was cut in each film to coincide with the aiming window. This film was purposely held so that its surface was not parallel to the mirror surface because it was found that the achromatic reflection from the front face of a film could seriously dilute the color of the signal reflected by the mirror. By making the film nonparallel to the mirror, the beam reflected from the front surface of the film was thrown harmlessly to one side of the aimed beam.

There is a question whether the best signaling mirror for survial use is one which gives a distinctly chromatic (red or orange) signal or one which gives a plain achromatic signal. A red or orange signal is more likely to attract the attention of the casual passer-by than an achromatic signal. However, the greater complexity of the device which gives the colored signal may offset the advantage of color. In general, apparatus for survial use should be as simple and foolproof as possible.