THE MULTISCOPE: A SIMPLE STEREOSCOPIC PLOTTER*

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THERE is a definite need for an inexpensive device that permits rapid and precise plotting to predetermined map scales from stereoscopic pairs of photographs. The need is greatest in the fields of military reconnaissance, forest management, and soil conservation where a practical stereoscopic plotter must be relatively portable, simple in design, and easy to operate. The multiscope, a simple stereoscopic plotter developed jointly by the Harvard Forest and the Dominion Forest Service of Canada, appears to meet these requirements.

Data from a single aerial photograph are commonly transferred to a map of a different scale by the use of grids, a reflecting projector, the Duoscope, the various Sketchmasters, or other simple applications of the camera lucida principle. Such instruments are rapid and easy to use, but have definite limitations, inasmuch as they do not ordinarily permit plotting from a stereoscopic image.

Plotting from stereoscopic pairs presents distinct advantages over plotting from a single photograph. In photographs of considerable relief, the use of orthogonal plotting devices greatly reduces image displacement caused by topographic relief. Detail is much clearer in the stereoscopic image. Land forms, such as hills, ridges, valleys, and swamps, can only be plotted stereoscopically. In forestry applications, too, a stereoscopic image is essential for discerning and plotting the various forest types, age-classes, and condition classes.

Stereoscopic plotters now in common use do not meet the needs of military reconnaissance, forestry, and soil conservation. The various measuring stereoscopes equipped with plotting arms (such as the stereo-comparagraph and the contour-finder) do not permit the orthogonal plotting of a stereoscopic image. Furthermore, such instruments do not, in themselves, permit the changing of scale in the course of the plotting operation. More elaborate instruments such as the KEK plotter, the Multiplex system, and the Aerocartograph are too immobile, expensive, and slow for many applications.

The need for a simple stereoscopic plotter was suggested by problems arising from a research project in the application of aerial photography to forestry.[1] The idea of the multiscope arose from a visit of the senior author in August, 1944, to the aerial photography section of the Dominion Forest Service in Ottawa, Canada, where he and George R. Sonley of the Service developed the principle, and constructed the first crude model from parts of several different types of experimental duoscopes. The instrument described in the present paper was constructed at the Harvard Forest by the junior author in December, 1944, and is being used successfully on a variety of problems.

BASIC PRINCIPLES

Basically, the multiscope is simply the incorporation of semi-transparent mirrors into the standard mirror stereoscope. By inserting one or two such mirrors next to the eye, another image can be superimposed on the stereoscopic image. The use of an appropriate lens or lenses eliminates parallax errors in plotting, and permits the eyes to focus on the two photographs and a map at

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* Editor's Note. It is believed that other similar instruments are near completion, and it is hoped that articles regarding them will be available for publication in the near future.

[1] Carried on by the authors representing Harvard University, in cooperation with the Fairchild Aerial Surveys, Inc., the Polaroid Corporation, the United States Forest Service, and other organizations, both public and industrial.

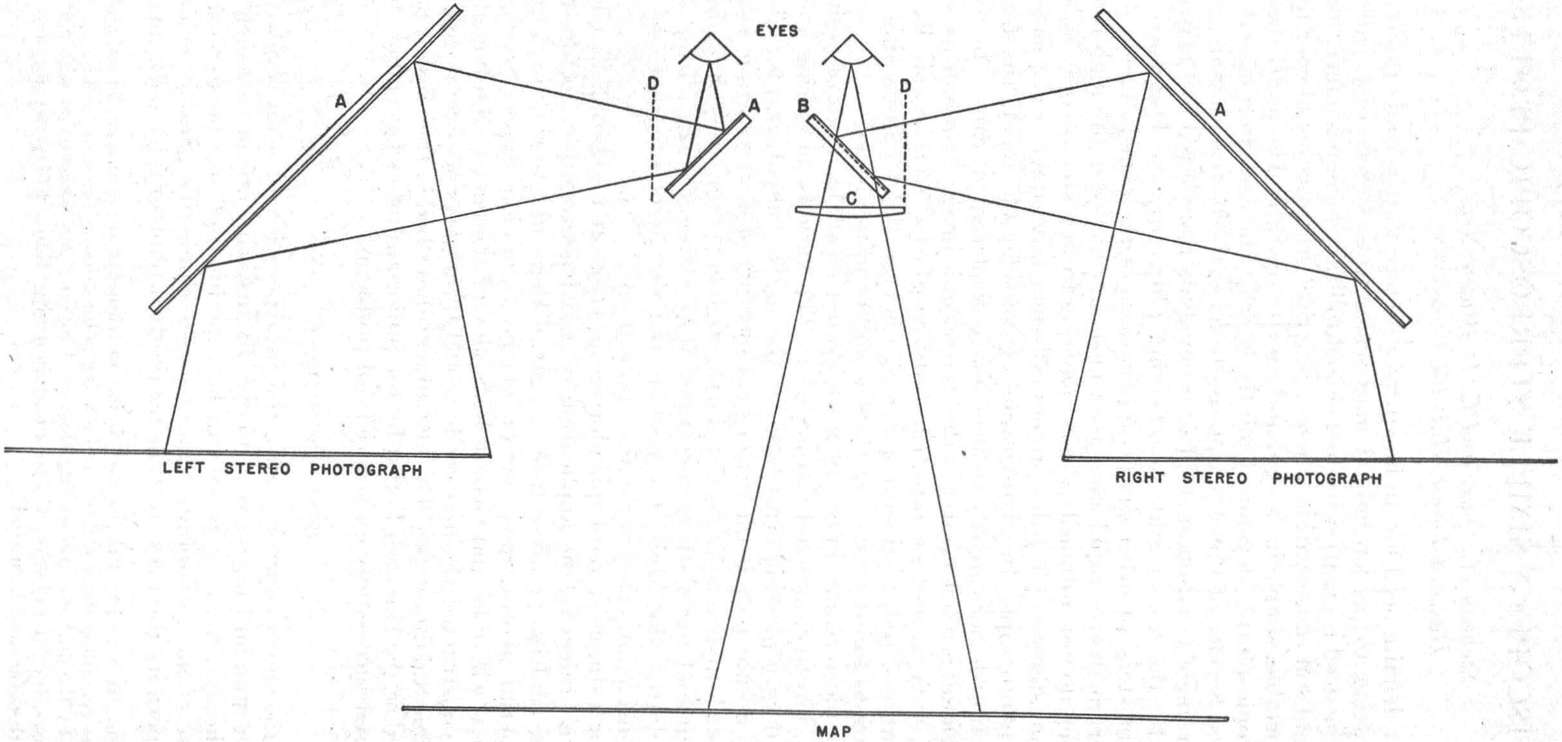

FIG. 1. OPTICAL DIAGRAM OF NON-ORTHOGONAL MULTISCOPE. A. Full-silvered mirror. B. Semi-transparent mirror. C. Lens to equalize optical distances, map-to-eye and photograph-to-eye. D. Plane in which lenses are inserted if photographs are nearer to eye than map.

the same time. By having the large end mirrors adjustable horizontally and the entire instrument adjustable vertically, a wide variety of changes in scale can be carried out. Thus, the operator sees his pencil and map with the stereoscopic image optically superimposed. He can then trace anything in the image onto the map.

The principle of the multiscope in its simplest form is illustrated in Figure 1. The images of the right and left stereo photographs are reflected by mirrors "A" and "B" to the eyes. Merged, they produce a stereoscopic image. The three "A" mirrors are full-silvered, as in the ordinary stereoscope. One of the eye mirrors ("B"), however, is but semi-transparent, enabling the operator to see the map at the same time that he sees the stereoscopic image. When but one semi-transparent mirror is used, the plot is that of the single photograph viewed with that mirror. A true plot of the fused image (i.e., an orthogonal plot) can be obtained when two semi-transparent mirrors are used (Figure 2).

Scale is regulated by changing the distance from the eye to the photographs, and the distance from the eye to the map. If the photographs are closer to the eye than the map, the stereoscopic image is enlarged on the map. If the map is closer, the stereoscopic image is reduced. Regardless of the actual distances involved, the optical distances of the map and the photographs from the eye must be the same if the eye is to focus on both the map and the stereoscopic image at the same time, and if errors in plotting due to parallax differences between the images are to be avoided. This adjustment is accomplished by the insertion of correcting lenses into the optical system; one or two lenses, depending upon the design, being inserted in plane "C" if the map is closer to the eye than the photographs (i.e., in reduction work), and a pair of lenses being inserted in planes "D" if the photographs are closer to the eye (i.e., in enlargement work). A series of interchangeable lenses of different focal lengths are used, covering a wide range of scale change. The choice of a lens or lenses for a given job depends upon the desired scale change and the desired image distances. The interchangeable lenses are essential. Without them, it is difficult or impossible for the eye to focus on both the photographs and the map. Furthermore, unless the optical distances are carefully balanced, considerable parallax differences between the superimposed images are introduced, and the precision of the mapping is impaired.

CONSTRUCTION

The multiscopes thus far constructed have been largely experimental in character. The Dominion Forest Service of Canada is modifying models of the duoscope[2] into a multiscope by changing the center piece to accommodate a semi-transparent mirror. The models built at the Harvard Forest (Figure 3) have been designed to obtain the utmost flexibility without regard to portability, in order to permit the exploration of the range and possibilities of the instrument.

Certain refinements have been found to be essential. To be practical, the instrument should meet all the specifications of a high grade mirror stereoscope. The use of first-surfaced mirrors is preferred. Second-surfaced mirrors may be used but do not reflect as much light and create "ghost images" which tend to be confusing to the operator.

The entire instrument can be raised or lowered to vary the distance from the eye to the map. This adjustment is accomplished in the pictured model by the use of a flexible parallelogram, but any other suspension may be used. An-

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[2] Seely, H. E. 1938. Air photographs as used by the Dominion Forest Service. Journal of Forestry 36: 1035–1038.

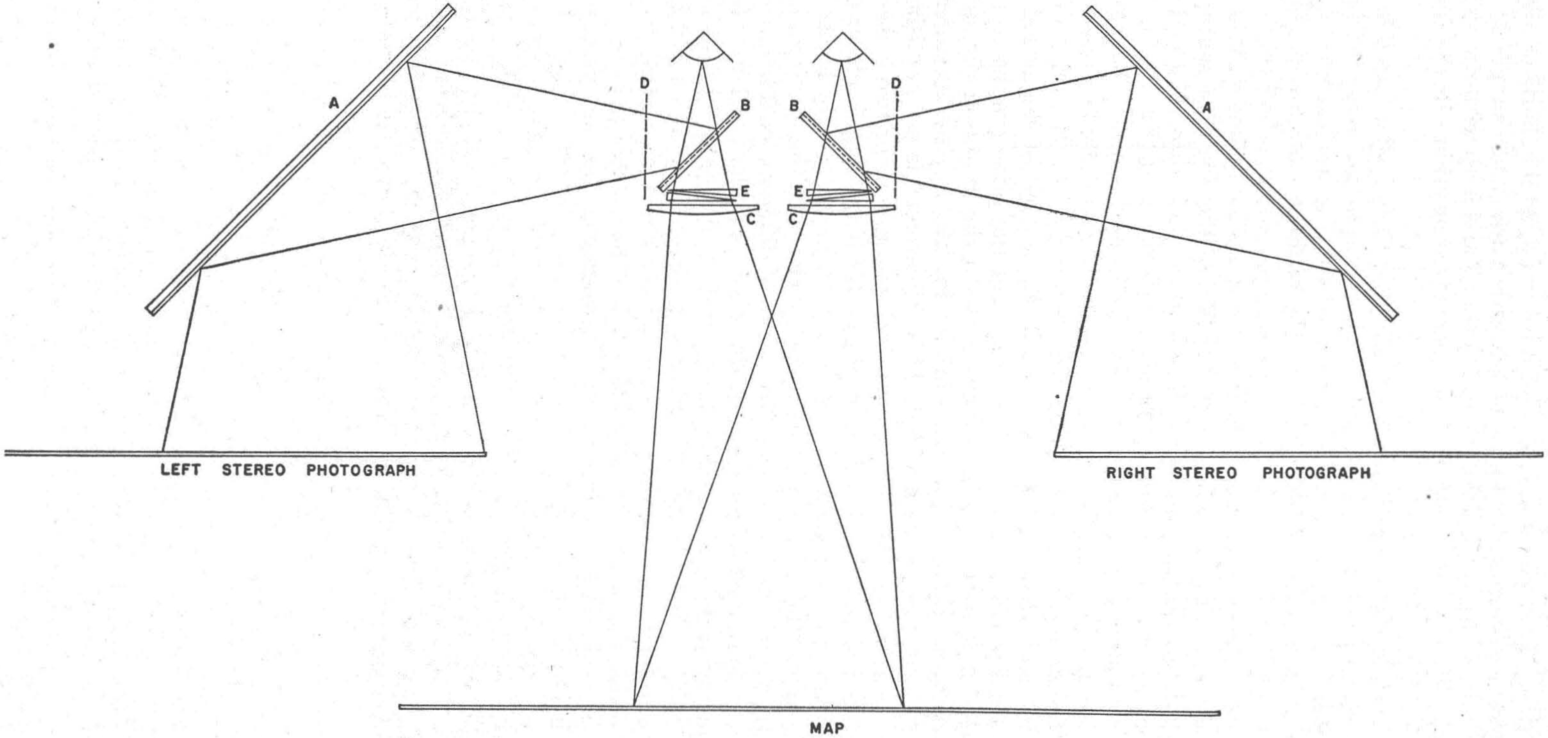

FIG. 2. OPTICAL DIAGRAM OF ORTHOGONAL MULTISCOPE. A, B, C, and D as in Fig. 1. E. Coupled rotary prisms.

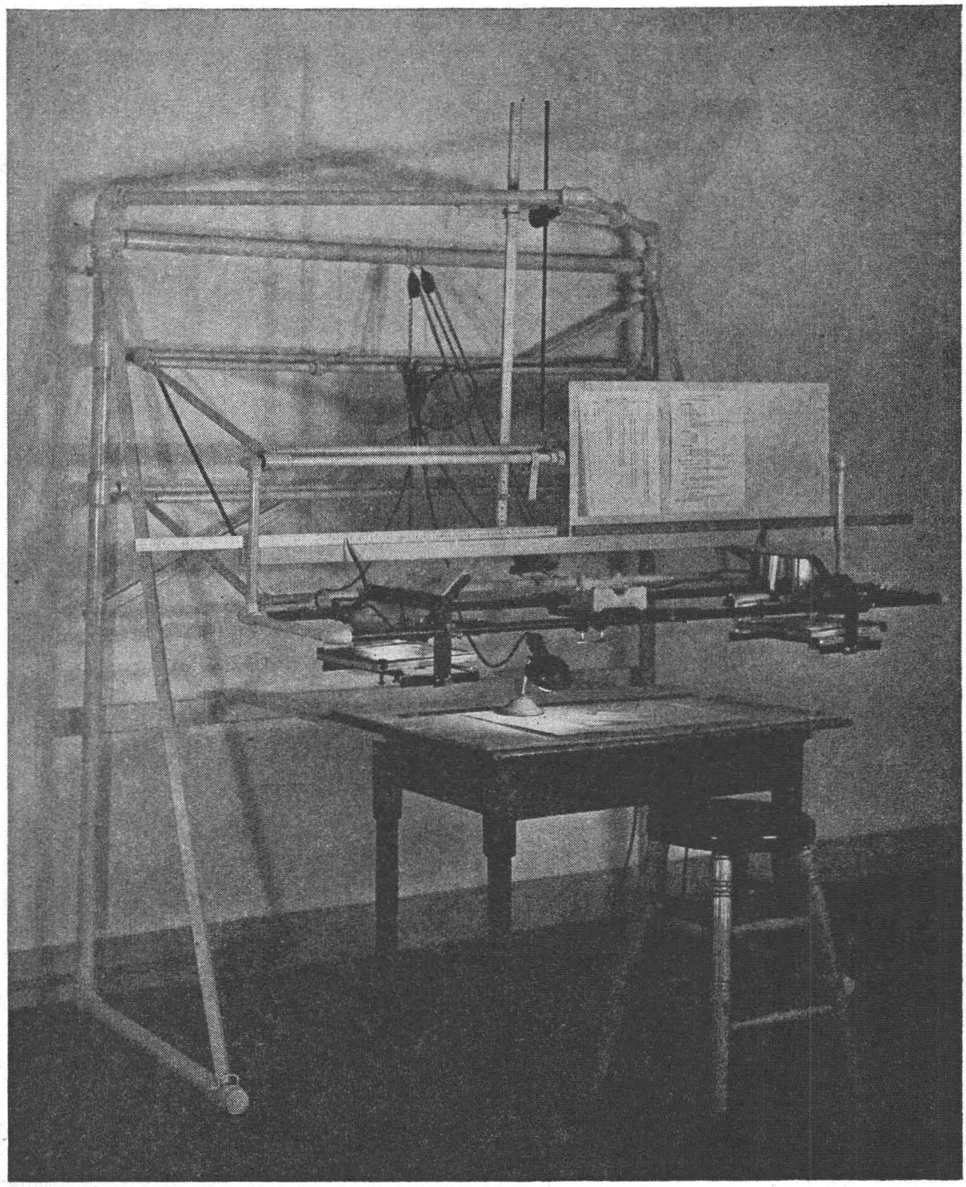

FIG. 3. EXPERIMENTAL MULTISCOPE AT THE HARVARD FOREST.

other alternative would be to regulate the height of the drafting surface rather than that of the instrument. The eyepiece must not be so close to the map as to interfere with drafting, nor too far above the map to prevent the observer from drafting. Thus, the practical range of elevation of the instrument is from about 18 to 70 centimeters above the drafting surface.

The large mirrors are adjustable in that they may be set at varying distances from the eyepiece. The photographs must be less than 30 centimeters from the eye mirror to obtain the maximum enlargement, which is about 3× without supplementary lenses. They must be about two meters from the eyepiece to obtain a reduction of 10×. This range may be obtained either with very long horizontal tracks for the sliding mirrors, or with a device permitting the lowering of the photograph.

The mount for the photograph may be fixed in a level position, but we have found that a flexible mount is preferable, allowing easy alinement and adjustments for tip and tilt. This is particularly important when the photographic image is to be projected onto a base map.

In the non-orthogonal design, the semi-transparent mirror is best inserted in the eyepiece for use by the right eye, as that eye is commonly dominant. Various reflection-transmission ratios may be used. Experiments with a mirror reflecting and transmitting equal amounts of light ($R:T=1:1$) have shown that such a mirror is satisfactory provided that light on the various objects is carefully controlled. A semi-transparent mirror reflecting three times as much light as it transmits ($R:T=3:1$) has been found to be particularly satisfactory. The greater reflectance from the dark photograph just about balances the lesser transmission from the bright surface of the map.

TABLE 1. MULTISCOPE ADJUSTMENTS
+1.00 DIOPTER LENS

M[a]	U[b]	X[c]
1.2×	17 cm.	23 cm.
1.3	23	33
1.4	29	43
1.5	33	53
1.6	37	63
1.7	41	73
1.8	44	83
1.9	47	93
2.0	50	103

[a] Magnification. May be either reduction or enlargement.

[b] Distance from lens to map in reductions, and from lens to photograph in enlargement.

[c] Distance from midpoint of center mirror to photographs in reductions, and from midpoint to map in enlargements.

If the multiscope is in proper adjustment, there is no parallax, but a maladjustment of as little as one centimeter is sufficient to create a noticeable amount. Consequently, it is difficult to eliminate parallax by trial and error. To facilitate adjustment, tables have been prepared based upon the formulae:

$$M=\frac{v}{u} \qquad \frac{1}{u}-\frac{1}{v}=\frac{1}{f}$$

where M is the scale change desired (either enlargement or reduction), u is the distance from the lens to the object, v is the distance from the lens to the image, and f is the focal length of the lens. If all values are expressed in meters, $1/f$ is the power of the lens in diopters. These tables give the correct readings at which the photographs and the map should be set for a given reduction or enlargement and a lens of a given power. A portion of this table covering the use of a lens of plus one diopter is given in Table 1. We have found that a series of lenses ranging in 0.50 diopter intervals from +0.50 to +5.00 diopters fills practically every need. A smaller series, ranging in one diopter intervals from +0.50 to +4.50 diopters is ordinarily sufficient. The observer in most cases will have a choice of several lenses for a given scale change, and can choose the one permitting the use of the most desirable distances. The scope of the instrument can be materially increased, and its size decreased by the incorporation of a more complex lens system. This permits the regulation of image size by optical methods rather than by mechanical methods.

When two semi-transparent mirrors are used, the plot is orthogonal. As this design is bisymmetrical, eye strain is minimized. The chief disadvantages are (1) the difficulty of adjustment so as to avoid a double image, and (2) the problem of avoiding parallax errors in plotting when a spatial stereoscopic image is superimposed onto the flat plane of the map.

A double image will be seen on the map unless the photographs are so placed that the angle of convergence necessary for the stereoscopic image is the same as the angle necessary for having the eyes converge on a single point on the map at the same time. This adjustment is not particularly difficult if the photographs and the map are at the same distance from the eye. In such a case, no lenses need be used, and no scale change is involved.

With any desired scale change, a double image may be avoided by the introduction of coupled rotary prisms ("E" in Figure 2) into the optical system, so as to equalize the required angles of convergence. Optical distances are equalized by the addition of the proper lenses as described above. The use of coupled rotary prisms under the semi-transparent mirrors, an invention of the junior author, not only permits the elimination of a double image, but also permits raising and lowering the plane of the map in relation to the plane of the spatial stereoscopic image. Thus, the operator can continually manipulate the rotary prisms as he plots so that his pencil is always tracing the image where it intersects the map plane. This permits the elimination of parallax errors in plotting caused by the spatial three-dimensional image being superimposed upon the two-dimensional map plane.

The use of rotary prisms also permits contour mapping and spot elevation determinations. The former is possible by setting the stereoscopic image to intersect the map at a given datum plane, and then tracing the line of intersection, thus creating a contour on the map. Spot elevations can be determined by placing any desired reticule on the map table and then raising or lowering the image by means of the rotary prisms so as to place the reticule in the desired plane in regard to the image. This method permits the use of a great variety of reticules such as white marks on black paper of any design (dots, crosses, circles, etc.), and three dimensional reticules (pyramids, balls, etc.). For use in contour mapping or in elevation determination, the rotary prisms must be calibrated.

If desired, the spatial image created by the multiscope may be measured and plotted in the same manner as that created by the Multiplex projector. The Multiplex tracing table or similar device can be used with the multiscope to determine tree heights, plot contours, and plot map detail accurately.

The multiscope is based upon the use of optical methods to change scale rather than the use of the pantographic principle. Although this is advantageous in that it permits maximum flexibility and simplicity, it is disadvantageous in problems requiring a large reduction of photographic scale where the photographs are far removed from the eye. In such cases, the delineation and interpretation of detail is apt to be difficult. This shortcoming can be met by using any standard type pantograph in conjunction with the multiscope. The major change in scale would then be made by the pantograph, while minor adjustments in scale would be made optically with the multiscope. Such an arrangement would combine the advantages of pantographic reduction with the simplicity and flexibility of the multiscope.

APPLICATION

The instrument described above has certain definite advantages over others now in use. It is simple, inexpensive, and easy to use. With proper engineering, it would be highly portable. Because it permits plotting from a stereoscopic image, it has many of the advantages of far more complex instruments and few of the disadvantages of other simple instruments. By eliminating the use of the pantograph principle to change scale in favor of a simple optical method, it acquires great flexibility. Since errors in plotting due to parallax are largely eliminated, the position of the head is not critical, an advantage permitting greater accuracy and greater ease of operation. Perhaps the most important advantage of the multiscope, however, is that the operator can always see everything he is doing. He is looking at both photographs and map at the same time. He can draft lines on the map, make erasures, and label the map as he proceeds, all without taking his eyes from the stereoscopic image. This permits the greatest possible speed and ease of operation. With the multiscope, photographic detail can be transferred to maps without any markings being made on the photographs.

The multiscope is so named because of the variety of forms in which it may be used. Simply by interchanging full-silvered and semi-transparent mirrors in the eyepiece, the instrument may be used as (1) a mirror stereoscope, (2) a dluoscope, (3) a camera lucida, (4) a non-orthogonal stereoscopic plotter, and (5) an orthogonal stereoscopic plotter. Both designs of stereoscopic plotters have their advantages. The non-orthogonal type (with one semi-transparent mirror) is simpler, easier to adjust, more rapid and more flexible. It is sufficiently accurate for plotting details on level or relatively level terrain. The orthogonal design (with two semi-transparent mirrors) is useable in plotting details of any terrain accurately. With it, tree heights and elevations can be accurately determined with the addition of coupled rotary prisms under the semi-transparent mirrors, or a device similar to the Multiplex tracing table. With it, also, contour mapping is possible.

The values of the multiscope in the solution of certain problems has already been demonstrated. Among these are accurate forest type mapping to an enlarged scale, generalized type mapping reduced in scale and projected onto a U. S. Geological Survey Topographic Map, farm and timber property mapping, and military reconnaissance mapping. Generally speaking, the multiscope will prove of value wherever it is desired to project any stereoscopic image onto any plane surface, at either the same or a different scale.

ANNOUNCEMENT

THE SECRETARY-TREASURER reports that a complete stock of emblems has been ordered, and it is expected that delivery will be made in the near future. The stock will consist of bronze, silver and gold pins, charms, and buttons. The bronze charms will probably not be received until mid-September, but the remainder of the order is due now.

Any orders now received will be held until the supply arrives. The emblems are sold at cost, the prices being as follows:

	Pin	Charm	Button
Gold	$6.25	$6.25	$6.25
Silver	1.00	.75	.75
Bronze	.75	.75	.75