THE CAMERA LUCIDA FOR AERO-MAPPING*

J. L. Buckmaster
Mechanical Engineer, U. S. Geological Survey

SEMI-TRANSMITTING mirror devices have been used or considered for use in the transfer of detail from aerial photographs as long as we have had aerial photography. E. Deville, Canadian scientist, had developed, by 1901, a stereoscopic plotter for terrestrial photographs in which semi-transmitting mirrors were used. This paper will discuss the proposed mapping use of the Camera Lucida, as semi-transmitting mirror devices are termed, and of several types of Sketchmaster in particular. It is assumed that if the reader is not somewhat familiar with the Vertical Sketchmaster he will refer to one of the manuals listed below.[1] Attempt will be made herein to present new or pertinent data which is not readily available in published material.

It is well understood, that in using a Camera Lucida device the eye receives two superimposed images, one from the photograph and one from the map manuscript. Each of the two images tends to confuse and dim the other, and if additional images or extraneous light enter the eye simultaneously, it is readily seen that the first-surface mirrors and good durable semi-transmitting mirrors developed in the late 'thirties were prime factors in making a practical Sketchmaster. Useful notes on the use of the instrument can be gained from reflection on the problems of the past. The mirrors must be clean and in good condition to prevent extraneous light from entering the eye. Second surface mirrors are to be avoided unless given non-reflective coatings to prevent double reflections. Since each image tends to dim the other, the ratio of their brightness must be within fairly narrow, though not critically narrow limits. Adjustment of the ratio of light between the photograph and the map has not been stressed as it should be for the inexperienced operator. Sometimes more light must be directed on the map and sometimes more on the photo, as for example in tracing a white road, in which case the light on the photo should be dimmed in order to bring out the pencil line on the map, superimposed as it would be, on the white photo image of the road. If black ink is used instead of a pencil on the manuscript, the lines will be seen more sharply, permitting the illumination of the map to be dimmed and the photo image thereby brightened in appearance. Either a gooseneck 75 watt desk lamp or an adjustable fluorescent type desk lamp will furnish satisfactory illumination. The inexperienced operator keeps trying to improve his lighting, while the trained operator goes rapidly about his work, seldom making a change in the illumination.

There seems to be no substitute for a little experience in the use of Camera Lucida devices, for the problems of the novice soon begin to disappear with practice, and often without an evident explanation. If a black map manuscript and a white pencil is used, little light will reach the eye from the map, and the photo image will appear almost as bright as though it were observed directly. In line with this fact it is convenient to have a small piece of black paper handy which may be flipped over the map manuscript momentarily when it is desired to see detail on the photo more clearly. A low oblique angle of lighting may be used on the map if it is desired to illuminate the pencil or pen more than the map manuscript.

* Published by permission of the Director, U. S. Geological Survey.

[1] Church, Earl. Elements of Aerial Photogrammetry. Syracuse University Press, 1944, pp. 59, 92, 93.

Aerial Phototopography, TM 5-240, War Department. Government Printing Office, 1944, pp. 56–58.

The question is frequently raised as to why two Camera Lucida instruments are not coupled together and the photographs viewed stereoscopically while sketching on the map. This has often been tried, sometimes successfully, but until one has mastered the single photograph instrument he will save time by making his stereoscopic examination first, outlining on the photographs the features he intends to transfer later to the map. At least two types of stereoscopic

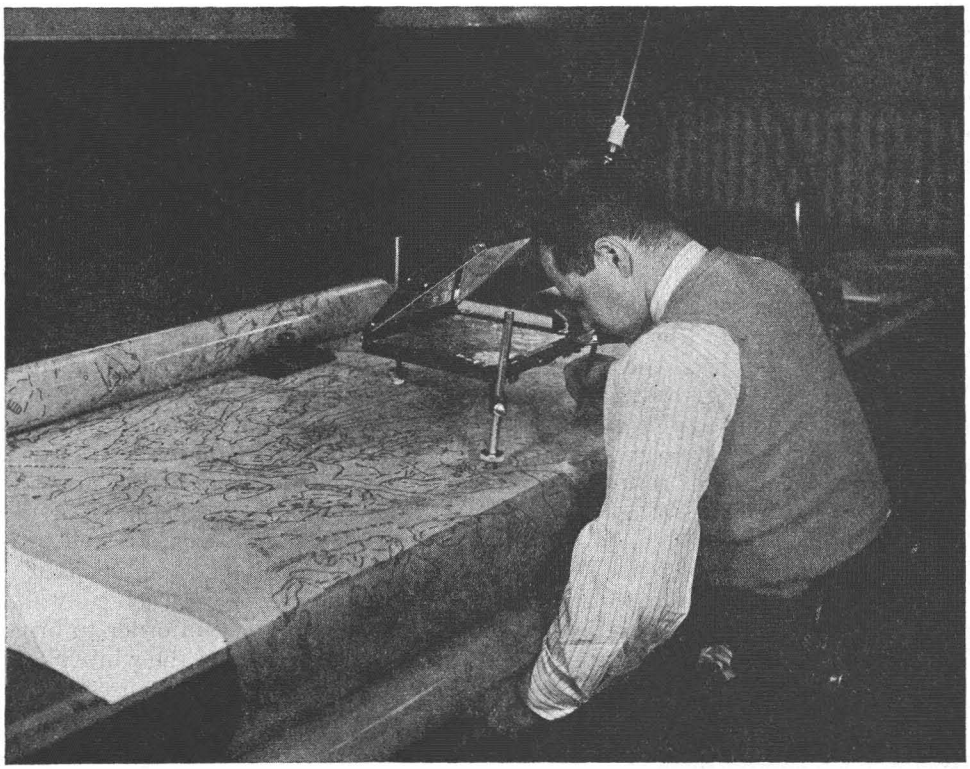

FIG. 1. The Vertical Sketchmaster Applied to Charting.

three dimensional "split-image" plotters[2] are now undergoing development, and the writer believes a very useful low-cost medium accuracy plotter is possible by such methods, but only after getting down to details is it realized that such development will require much time and effort.

Vertical Sketchmasters have undergone considerable development in form but are still basically similar to the Geological Survey's first model of 1941,[3] Figure 1, which was called a "Lucidagraph" by the author, but dubbed "Sketchmaster" by the first users, that name thereafter being accepted. One of its main advantages is the ease with which it can be adjusted to correct for the tilt of the aerial photograph. The instrument has a perspective distance or length of optical path from photograph to eye of about $13\frac{1}{2}$ inches. The instrument can be tilted to exactly correct the tilt of the photograph only if the principal dis-

[2] See "The Multiscope"—PHOTOGRAMMETRIC ENGINEERING, Volume 9, No. 3, Sept. 1945.

[3] Pat No. 2,342,640 Aero Service Corp., Philadelphia, Pa., and Harrison C. Ryker, Inc., Berkeley, Calif., exclusive authorized manufacturers for commercial sales.

tance (effective focal length) of the photograph is 13½ inches. Practically, however, the principal distance of the photo may be 6 inches or less, and the distortion of the sketched image will be negligible so long as tilts are not in excess of 5 degrees. (See Fig. 2.) In working with photos of shorter principal distance the required tilt of the instrument for proper adjustment will be greater than the tilt of the photograph by the same ratio as the Sketchmaster's optical distance (13½ inches) is greater than the photograph's principal distance. Only when the principal distance of the photograph is 13½ inches should the tilt of the instrument be the same as that of the photograph, and for photos of still longer principal distance the instrument should be tilted proportionally less. The Sketchmaster will assume such tilts if the photo control image points are adjusted to the corresponding points on the map, or when roads or lines that are parallel on the ground are adjusted to apparent parallelism on the map.

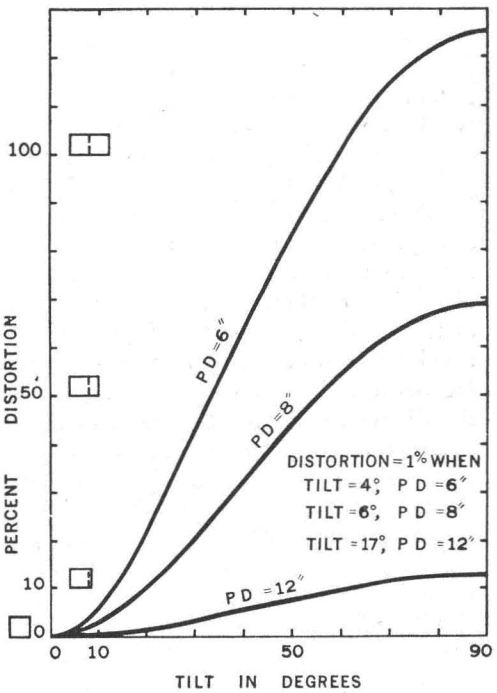

FIG. 2. Showing the distortion resulting from projection of tilted photographs having principal distances of 6, 8, and 12 inches in a projection device having a perspective distance of 13½ inches. The distortion is a linear exaggeration in one dimension and is best illustrated as changing a square into a rectangle. The curves are based on the photographs being mounted perpendicular to the line from their principal point to the perspective point of the device, and the projection plane being tilted for best rectification. True rectification is possible if the photograph is offset to a computed position, requiring its tilt to be known.

In adjusting a Camera Lucida instrument for tilt it is highly desirable that the photo image shifts as little as possible with respect to the map manuscript when the tilt adjustments are made. This condition will obtain if the intersection of the instrument's tilt axes lies near the center of the apparent photo image in the plane of the map. This condition is maintained in the Vertical Sketchmaster and is the main reason for the positions of the three supporting legs. It is interesting to note that while the captured German Camera Lucida instruments cost about twice as much to build as the American models and showed fine workmanship, adjustment for tilt was by a ball-in-socket photo plane, making tilt adjustments slower and less certain. The German models have a very convenient single knob for changing scale, but after the first photo of a project is adjusted to the map base the most used adjustments are those for tilt, except for areas of high relief.

The effect of relief has been disregarded in most of the above statements. The only completely satisfactory way of handling the relief displacement of aerial photographs is through the use of stereoscopic plotters which auto-

matically plot orthographically. In using a Sketchmaster, correction is made for these displacements by using a large number of photo control points, and by adjusting the height of the instrument to an optimum scale for the detail traced. Sometimes by giving the instrument an excessive tilt all of a large and comparatively uniform slope can be approximately fitted to the map manuscript.

No two mapping problems call for exactly the same treatment, but in a general way it may be said that the minimum number of photo control points practical for medium accuracy mapping of level country will be the nine points per photograph commonly used for radial-control; assuming that the scale of the photograph is not smaller than the publication scale of the map. For maps of higher accuracy and rough terrain it may be practical to locate photo control points as close together as one-half inch.

A recommended procedure in tracing detail is to start with the main drainage and proceed to the small drainage, raising the Sketchmaster to the best scale ratio as necessary and tracing off roads and other detail of the same general elevation as the sketching of the drainage proceeds. After completing transfer of the small drainage the ridge lines should be transferred, if wanted, the drainage heads connected with the small drainage and the culture of the higher levels transferred. The remaining culture and detail is then filled in. The most difficult detail to transfer will be that which lies on steep non-uniform slopes, as azimuth corrections must be made, but since the detail of the more level terrain is already in place, the problem is simplified considerably.

In transferring detail of relatively level terrain almost any sketching procedure may be followed, for the photo image will fit the map manuscript almost exactly, barring serious paper distortion or map control errors. When working on weak map bases in level country, the base can be "tightened" somewhat by paying attention to the long tangents of roads, railroads, power-lines, etc. and bringing the base into agreement.

The knurled adjusting screw at the base of each leg should bear an index mark so that the three screws can be given approximately equal rotation when changing scale, thereby maintaining the same tilt adjustment. After a little experience, the rotation necessary for any required change in scale can be estimated with fair accuracy. The threads of these adjusting screws should have a large lead or pitch to facilitate making rapid changes in tilt or scale.

Parallax is a common but unnecessary cause of inaccuracy in using the Sketchmaster. It is always associated with one of the images being more or less fuzzy and out-of-focus. Accurate work can be accomplished and this problem practically eliminated if the images are viewed through a small fixed aperture, the diameter of which is less than that of the pupil of the eye. It is more convenient when using the Vertical Sketchmaster, however, to use a suitable lens below the semi-transmitting mirror and to use a large aperture or viewing window.

When a Vertical Sketchmaster is used to transfer detail at a ratio other than 1:1, the insertion of the proper lens below the semi-transmitting mirror will perform two functions. It will eliminate parallax (Fig. 3b) or the apparent motion of the map plane with respect to the apparent photo plane when the eye is moved, and it will bring the map plane into exact focus with the apparent photo plane. If a black piece of paper is placed in the map position and a photograph is placed in the photo frame, the photograph will appear to be directly below the eye, due to the double reflection (Fig. 3a). The apparent distance from the eye to the photograph will be a constant and will obviously equal the length of the path of a ray of light from the photograph, to the large mirror, to the semi-

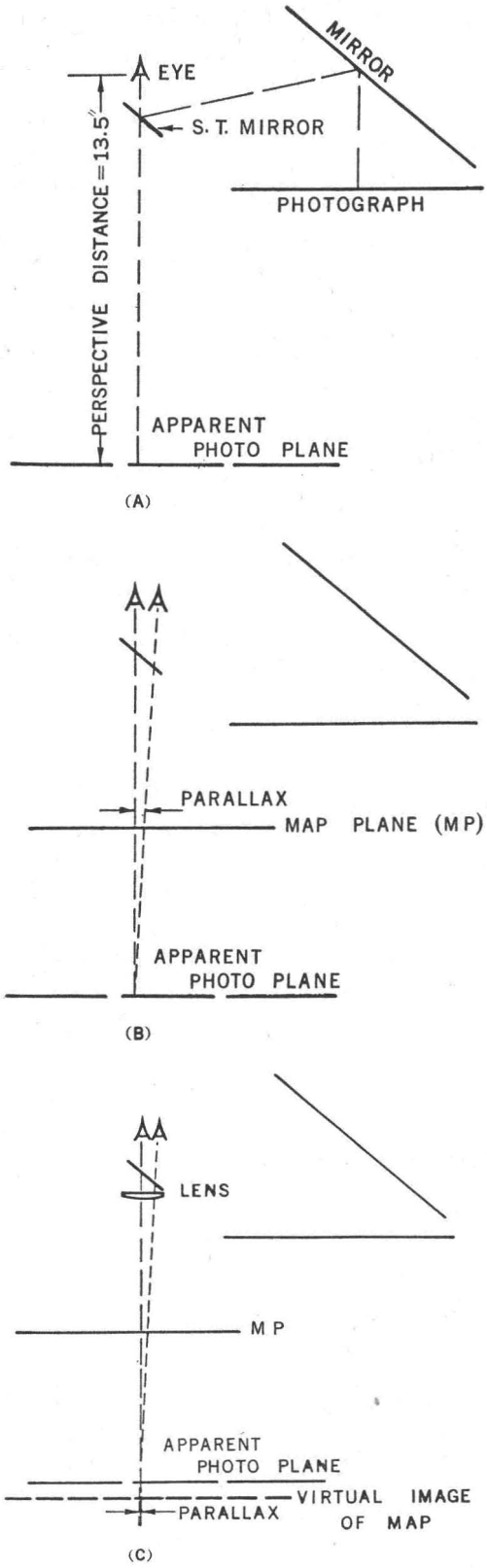

FIG. 3. Parallax Analysis.

transmitting mirror, and thence to the eye. When the eye is properly positioned at the closest comfortable point to the instrument this distance is about 13.5 inches. For any elevation of the instrument above the map plane there is a lens which, inserted in the lens clips below the semi-transmitting mirror will create a "virtual image" of the map plane in the apparent photo plane, approximately 13.5 inches from the eye. When this condition exists there can be no parallax, and both planes can be viewed in sharp focus, regardless of any lateral movement of the eye.

Since exactly the right lens is not usually at hand, the desired condition can be approximated only (Fig. 3c), but with a small assortment of lenses, a wide range of ratios may be obtained with very little parallax; providing the most nearly correct lens is used. If a positive lens is too strong, the virtual image of the map will be too distant, with respect to the apparent photo position, and the map will appear to move in the direction the eye is moved. When the map scale is larger than that of the photograph a negative lens will bring the virtual image of the map too close, and it will appear to move in a direction opposite to the movement of the eye. The easiest rule to remember is that if the lens used is too strong the parallax will be opposite in direction to the parallax when no lens is used.

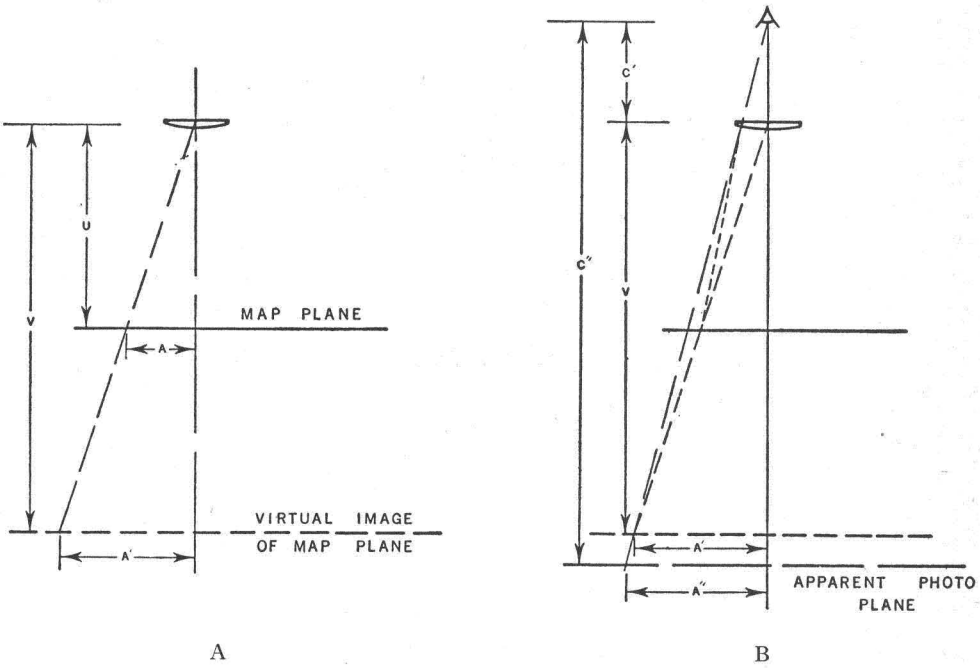

FIG. 4. Lens and Ratio Diagram.

The distances map-to-lens (U) and virtual image-to-lens (V), Figure 4a, follow the basic law of lenses,

$$\frac{1}{U}+\frac{1}{V}=\frac{1}{f} \quad \text{or} \quad \frac{1}{V}=\frac{1}{f}-\frac{1}{U}.$$

Referring to Figure 4a, when a positive lens is used, the focal length (f) of the lens is always greater than the distance (U) from lens-to-map. Consequently, the distance (V) is always negative, meaning that it is on the same side of the lens as the map, and the image is virtual. When a negative lens is used, (V) is also negative and the image is virtual. On looking through the instrument the map plane will appear to be, and for geometrical purposes is located at its virtual image.

The magnification of the virtual image, also in accordance with basic lens laws will be U/V. If the virtual image of the map lies in the apparent plane of the photograph the scale ratio of map to photograph will also be exactly U/V regardless of eye position. However, if the virtual image of the map does not lie in the plane of the apparent photo there will be an additional change in ratio which, referring to Figure 4b will be,

$$\frac{A'}{A''} = \frac{C' + V}{C''}$$

and since C' is approximately 2.5 inches and C'' is approximately 13.5 inches, this second factor becomes,

$$\frac{2.5 + V}{13.5} = .185 + .074V$$

The effective ratio of map scale to photo scale will be the product of the two factors, or

$$\frac{U}{V}(.185 + .074V).$$

For average work a set of seven lenses ranging in strength from a minus 1 diopter to a plus 6 diopter is satisfactory, but for more accurate work the set should include the intermediate half diopter lenses.

The Oblique Sketchmaster is a specialized device designed expressly to transfer detail from 60 degree[4] Trimetrogon oblique photographs having a principal distance of 6 inches. A one-eighth inch viewing aperture functions as a perspective point and prevents excessive parallax. The use of lenses in the Oblique Sketchmaster is ordinarily impractical, first because the distance from the aperture to the map varies over wide limits, and second, because changing lenses would change the rectification geometry and require a readjustment of the instrument for tilt and scale.

The maximum field of view obtainable through an aperture and double mirror system is not wide enough to cover the required area of a Trimetrogon oblique photograph if it is placed at its principal distance from the perspective point. In order to bring the required area of the oblique within the field of view and still obtain rectification it was necessary to resort to a principal of perspective and rotate the oblique 30 degrees about its horizon line,[5] from its proper position, a condition permitting true rectification to be obtained, but since the distance from an oblique photograph's perspective point to its horizon line changes with focal length and angle of tilt, the Oblique Sketchmaster is theoret-

[4] The tilt of high oblique photographs is expressed in terms of the camera's "depression angle" below the horizontal, which would be 30 degrees for Trimetrogon oblique photographs.

[5] Rotation 20 degrees in the improved model.

ically correct only for photos having a principal distance of 6 inches and 60 degrees of tilt.

While it is essentially satisfactory for all Trimetrogon reconnaissance mapping, a distortion of about one per cent results from each degree of tilt by which the oblique photograph varies from the standard sixty degrees. This could be

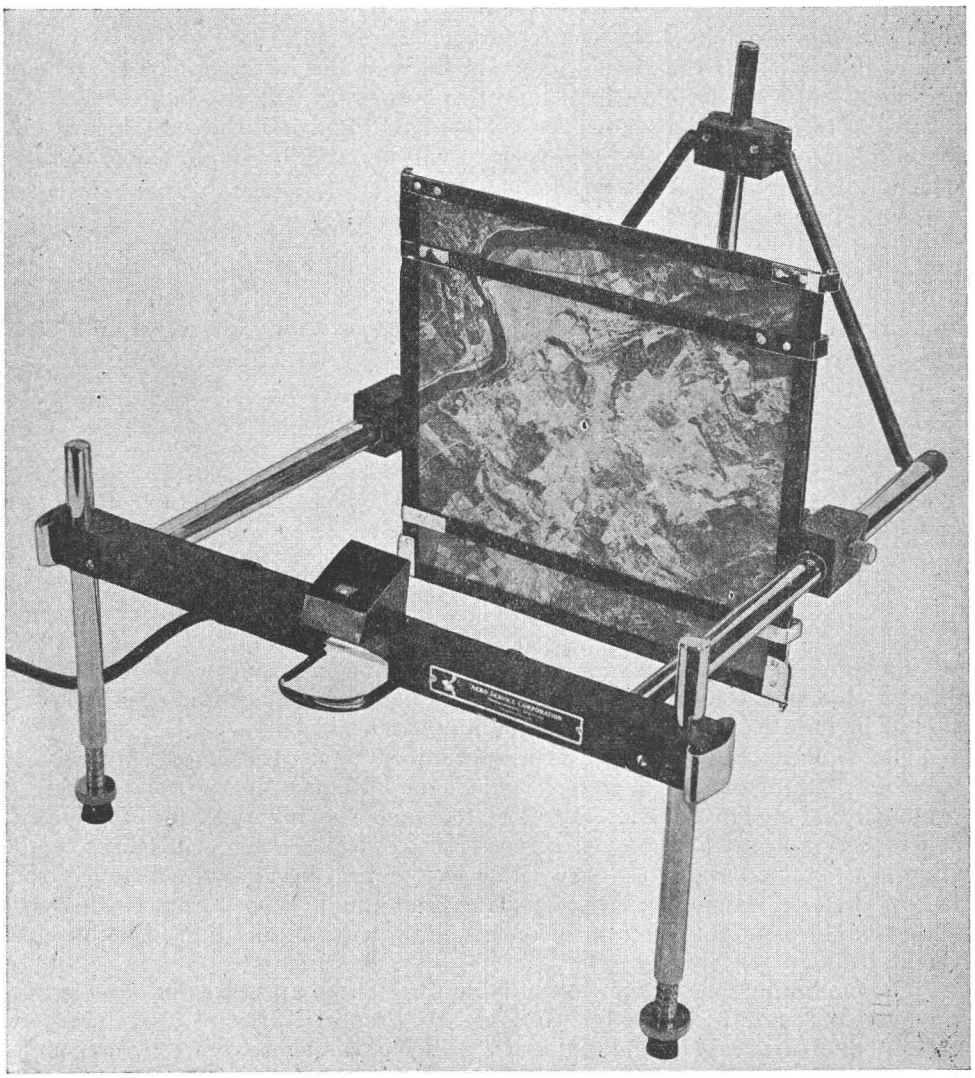

FIG. 5. Universal Sketchmaster (Courtesy Aero Service Corporation).

partly or completely eliminated by shifting the oblique up or down the holding frame in order to match the perpective distance to the horizon line, but few operators understand this principal and also, an essential part of the oblique might thereby be shifted outside the field of view. The instrument was improved considerably in 1942, but the only improved models known to have been constructed are those in use by the U. S. Geological Survey.

In 1941 a "split image" prism was developed having a viewing aperture, a full reflective and a semi-transmitting mirror surface (Fig. 7b). Because of its wide field of view, the prism made possible a "universal Sketchmaster" (Figs. 5 and 6) in which the photograph was always perpendicular to the line from its principal point to the effective perspective point of the instrument and in which

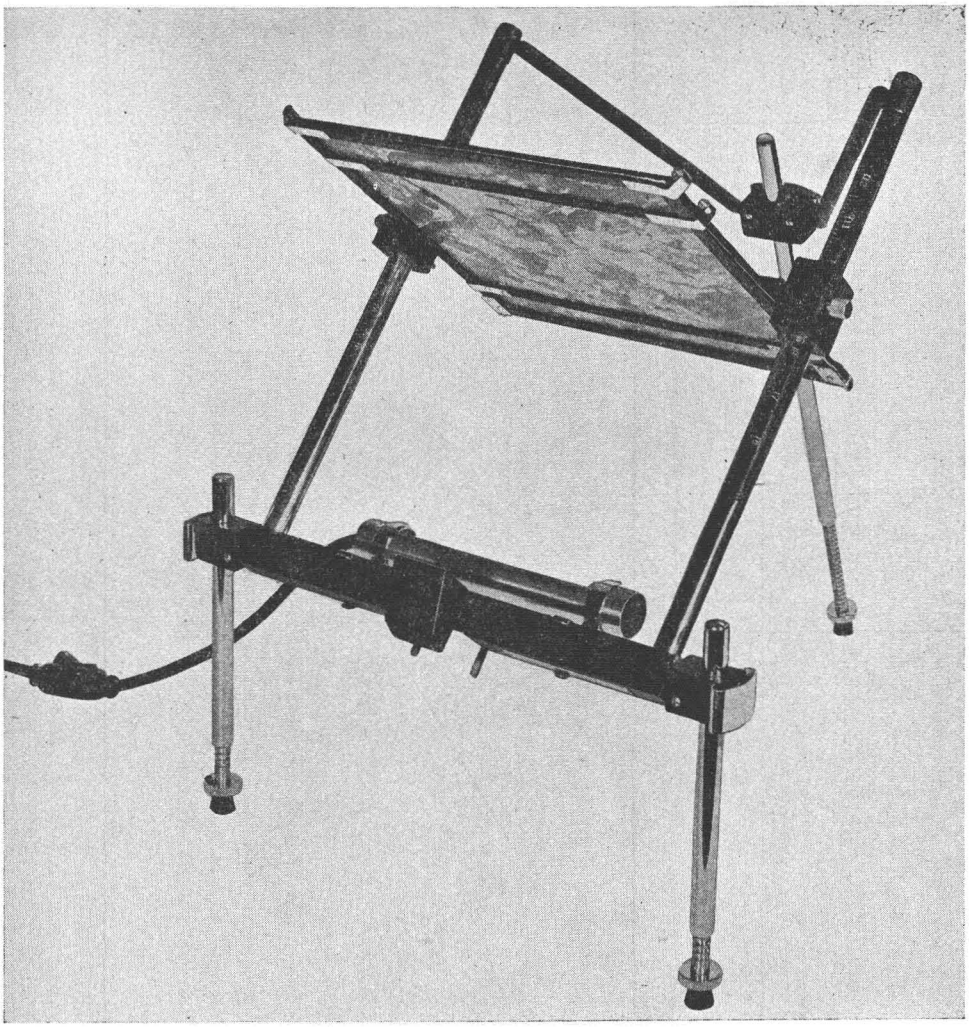

FIG. 6. Universal Sketchmaster (Courtesy Aero Service Corporation).

the perspective or principal distance of the instrument could be adjusted to match that of the photograph. The field of view is wide enough to cover the essential part of a Trimetrogon oblique at the 6-inch principal distance, making theoretically correct rectification possible for any angle of tilt. It is also suitable for vertical photographs, by moving the photograph to a 10-inch or greater perspective distance in order to bring the whole photograph within the field of view. For tilts of 5 degrees or less the resulting distortion is negligible as shown

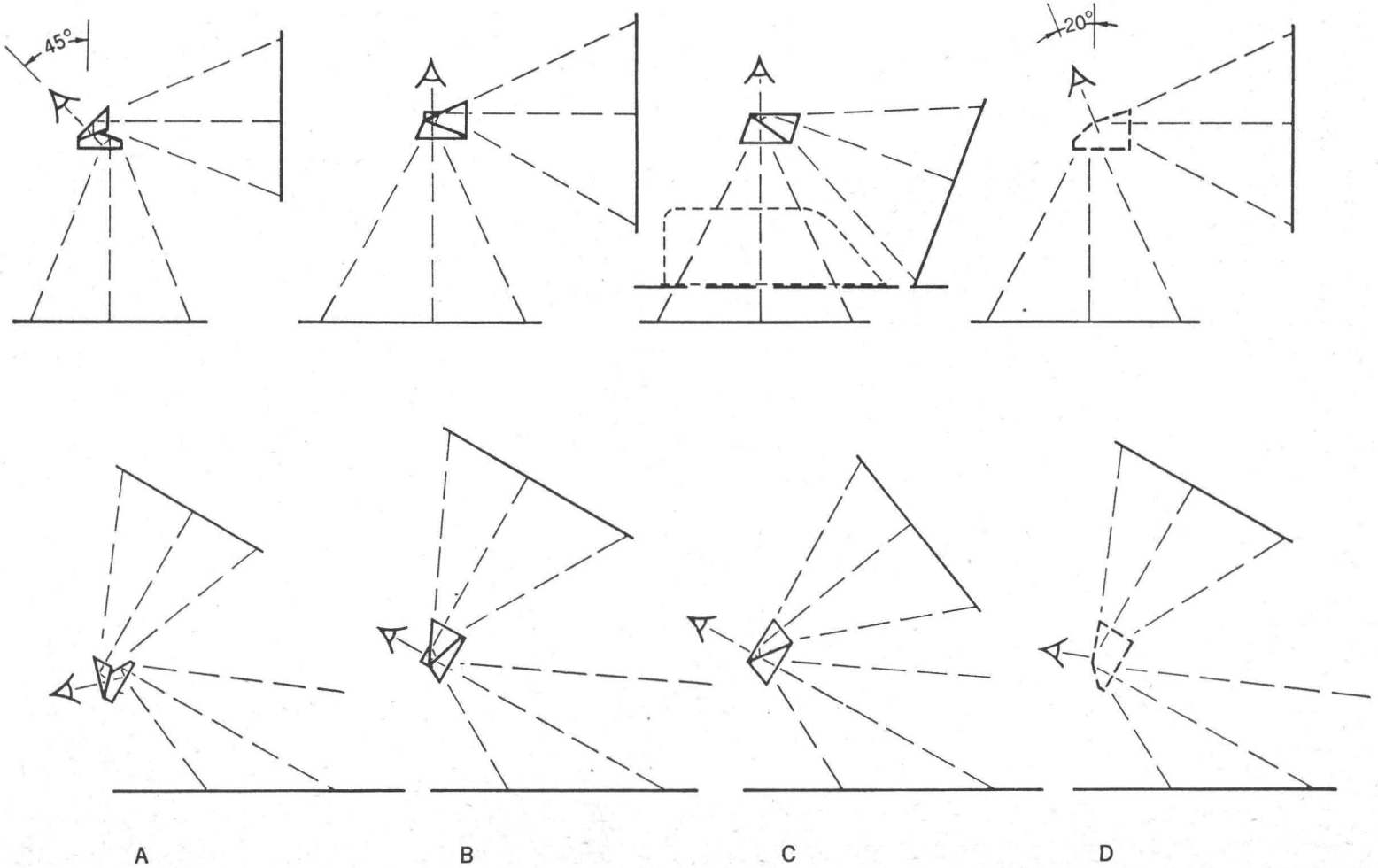

FIG. 7. Schematic Diagrams of Sketchmasters Using Various Prisms.

in Figure 2. Due mainly to the Oblique Sketchmaster's earlier development and use, the Universal model, though capable of more accurate work, never displaced it.

During the summer of 1945 the author attempted development of a prism which would have the advantages of the previous prism but with a more convenient viewing angle, and was successful (Fig. 7d), at least in his opinion.[6] A comparison of viewing angles is shown in Figure 7. It is hoped the new prism will be available by the fall of 1946. The seventy degree prism (Fig. 7c) is designed especially for oblique photographs, and is also suited to use with vertical prints, but since it cannot be adjusted as low without the photo frame touching the table its range in reduction is limited to about 1:2. Figure 7c shows by dotted line the use of a block on which the map may be placed in order to obtain reduction ratios of 5 diameters or greater. This scheme is adaptable to all the Sketchmasters, and while undesirable due to the distortion of the strong lens required, it may serve a useful purpose at times. For enlarging ratios of one to two diameters it is preferable to mount the Sketchmaster on a special three-legged rigid support to increase its stability.

In operation the Universal Sketchmaster is similar to the Vertical model, except that it may be adjusted in perspective distance to match the photograph, and it can be adjusted to almost any angle of tilt. It folds into a small space and operates over a wide range of ratios.

Lens clips are provided below the prism so that lenses may be used the same as with the vertical model. Ordinarily, no lens is used when sketching from oblique photographs, but if the principal distance of the photograph is considerably different than the distance from the prism to the center of the corresponding map area, the use of a lens is advisable. If two lenses are used for the same photograph to facilitate sketching first the foreground and then the background, the instrument must be readjusted in tilt and scale when the lenses are changed.

The use of a prism instead of two plane mirrors in the optical system has several advantages. Because the reflections take place within a glass of relatively high refractive index, a larger field of view is possible with a small ($1\frac{1}{4}''$) optical unit. The angles between the reflective faces cannot get out of adjustment and there is less danger of breakage. The mirror coatings are protected so that they are not subject to deterioration as from fingerprints, which will ruin first-surface mirrors in a year or less if not carefully cleaned off. Because of their small size, a better view of the photograph and better lighting is obtained. A point in favor of the plane mirrors is that with the Vertical Sketchmaster the images may be viewed through a half-inch opening instead of through a one-eighth or smaller aperture.

It is the writer's opinion that the Universal model in addition to being more accurate, when fitted with either prism c or d, Figure 7, will be more convenient to use than the Oblique Sketchmaster for Trimetrogon mapping.

Whether or not it will be more convenient to use with vertical photographs than the Vertical Sketchmaster is not yet known, but a guess is ventured that each instrument will have its proponents.

These instruments are not intended to replace the more complex and precise stereoscopic plotters, but to provide simple low-cost portable devices with which planimetry can be transferred to a manuscript efficiently and accurately.

[6] The prism used in captured German Sketchmasters was judged by the author to have too small a field and an angle of view unsuitable for oblique work (Fig. 7a).