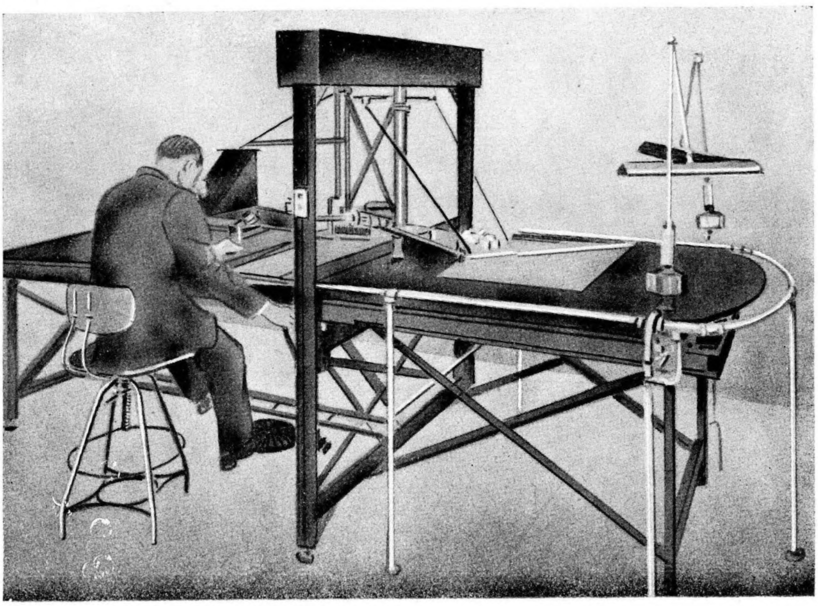

Fig. 1
The Reading Plotter.

THE READING PLOTTER

Extract from an article

by G. C. TEWINKEL, U.S. Coast and Geodetic Survey,
published in *Photogrammetric Engineering*, Vol. XIII, No. 2,
Washington, June, 1947, pp. 257-268.

In the Division of Photogrammetry of the U. S. Coast and Geodetic Survey, the stereoscopic mapping instrument has been in successful operation with nine-lens photographs since February, 1945.

This device is the crowning unit of four separate instruments, which includes the nine-lens camera, the transforming printer and the rectifying camera, each of which was developed under the direction of Commander O. S. Reading. Its parts were assembled and adjusted in Washington, D. C. by the Coast and Geodetic Survey.

The plotter is a precision instrument for producing an orthogonal projection of contours and planimetry from 35 × 35 -inch untitled photographs resulting from the special nine-lens camera of the U.S. Coast and Geodetic Survey. It was designed primarily for mapping at large scale in intricate coastal areas where control is sparse and where single-lens photography is at a disadvantage. The instrument is dependent upon the transforming printer to furnish a composite photograph equivalent to a single-lens, wide-angle, near-vertical one, from the one vertical and eight oblique views on the negative; and it is dependent upon the rectifying printer for the removal of camera tilt and for the change of scale.

The nine-lens camera[1][2] consists of nine lenses located essentially in a common horizontal plane in front of a film which is 23 inches wide. Eight of the lenses from a regular octagon with the ninth in the centre. The lenses are matched Ross 68° objectives of 8 1/4-inch focal length. The central lens functions in the normal manner. In front of each of the eight outer lenses is a coated steel mirror inclined at 19° with the vertical, which causes a 38° oblique reverse negative to be formed on the same piece of film in a position separate from the other views. The operation of the nine shutters is synchronized electrically. The film is maintained flat by means of a vacuum back. Forty-five marks are projected onto the film to serve as film measuring or fiducial marks. A clock face and a numbering device are also photographed on each negative. A roll of film is 200 feet long and contains 100 exposures. The camera weighs about 300 pounds without accessories.

The transforming printer[1] was developed in conjunction with the nine-lens camera, along with a device for centering the film in a holder and measuring the shrinkage as indicated by the fiducial marks. Corrections for the amount and direction of shrinkage are applied to the printer in the form of six separate adjustments coupled to dial gauges. The printer is built into a partition to give a photographic dark room on one side. The instrument is composed of two parts: one for projecting the oblique views and the other for projecting the central portion. The resulting transformed print is equivalent geometrically to a single-lens photograph of 135° angular field, 8 1/4-inch focal length, and taken from the flying height of the original negative. The print is tilted the same as the original camera, which is also that of the central chamber.

The rectifying camera[3] is equipped with a lens of 23-inch focal length to maintain a suitably narrow angular field and good optical characteristics; it is limited mechanically to use with near-vertical photographs. The planes of the negative, the lens and the positive (easel) are each normally horizontal, and may be rotated about each of two perpendicular horizontal axes similar to the x-tilt and y-tilt of the multiplex. Graduated circles and verniers are provided for reading the angular settings to the nearest minute. The negative or

(1) O. S. Reading: "The Nine-Lens Camera of the Coast and Geodetic Survey": "Photogrammetric Engineering", Vol. I, No. 5, pp. 6-13, 1935 and Vol. IV, No. 3, pp. 184-192, 1938. See also: "Hydrographic Review", Vol. XIII, No. 2, Monaco, November 1936, pages 131-137.

(2) "Manual of Photogrammetry": American Society of Photogrammetry, Pittman Publishing Company, New York, 1944.

(3) "Manual of Photogrammetry".

upper plane, which holds the transformed print in position by vacuum, is illuminated with reflected light. The resulting print is ordinarily negative in tone and position, and requires a second photographic step to produce a positive print. The instrument is also equipped with a focal plane glass plate and transmitted illumination for use with film. It is automatic focus when the planes are not tilted. The rectifier may be used either with computed data, or else with a rectification templet, the settings being coordinated by means of empirical rules and graphs.

The Reading plotter (figure 1) is designed to operate with photographs that have no tilt, which presumes rectification. The map sheet is produced at the datum scale of the photographs, which presumes that all required changes in scale are done prior to the plotting operation and may be combined with the rectification operation, whether the change is due to irregular flying or to the desire for a scale different from that of the negative. Full theoretical correction is accomplished mechanically for the reduction of all planimetry to datum regardless of elevation differences, up to the limit of half the flying height. Elevation readings are obtained from an indicator graduated in equally spaced divisions of one-thousandth of the original flying height of the air camera, with tenths of a division estimated. The relation of indicator elevations to flying height remains unaltered by any intermediate common scale change of the photographs.

The stereoscope is suspended so that it may be moved freely above the surface of the photographs. It is maintained parallel by steel bands in a manner similar to some drafting machines. Movement of the stereoscope is accomplished by means of a convenient handle whose operation is similar to a pencil. The operator views the photographs from a seated position, obtaining a two-time magnification and a field of view of about two inches in diameter. The instrument may be operated from either side by rotating the eyepieces through 180°. The floating marks are fixed small black round dots on reticles mounted in the optical trains of the stereoscope. The operator moves the stereoscope to make the floating index mark appear to trace the photographic images, which drives the pencil point of the pantograph correspondingly. The floating mark is made to appear in contact vertically with the image by the use of a foot wheel. The objectives of the stereoscope are about forty inches apart, and the stereoscope is mounted off-centre.

The photographs are clamped with their nadir points at the centres of their respective tables. They are orientated by rotating the tables individually to obtain stereoscopic fusion. They may be separated by the horizontal motion of the outer table through a special hand wheel. In practice, the elevation of a given control station is set on the indicator by the rotation of the footwheel, and then the photographs separated with the hand wheel until stereoscopic vision is afforded and the floating mark rests on the image. This sets the air base. The floating mark is made to ascend or descend by use of the footwheel which changes the separation of the photographs also by moving the outer photograph. A limited transverse motion of the inner photograph can be used for the removal of any residual y-parallax, which amount is registered on a counter.

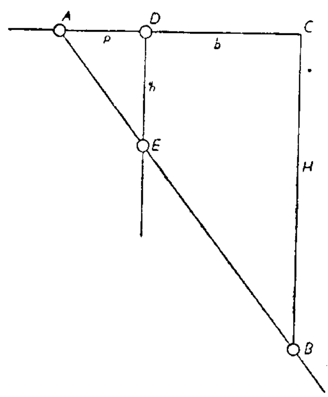

Fig. 2

The effect of rotating the footwheel is four-fold : (1) It causes an apparent change in the vertical position of the floating mark ; (2) It operates a mechanical computer to show the result in terms of elevation difference on the indicator; (3) It changes the plotting scale of the pantograph correctly as a function of elevation; and (4) It changes the position of the map sheet table to correspond to the change in the operating dimensions of the pantograph, which is explained more fully later.

The operation of the computing device as driven by the footwheel is quite fundamental. The triangle *ABC* and the line *DE* (fig. 2) represent a mechanical linkage which is located beneath the outer photograph. A fixed right angle is at *C*, and a fixed distance *BC* represents the flying height *H* of the photographs. The distance *CD* is generated by the air base hand wheel and represents the photograph base *b*. The line *DE* is maintained perpendicular to *AC*. The distance *DE* is generated by the footwheel which moves point E vertically representing a difference in elevation *h*. This motion forces a motion *A* along *CD*. The point *A* is attached to the outer photograph and hence represents difference in parallax *p*. From the geometric relationship of similar right triangles set up by the mechanism,

$$\frac{h}{p} = \frac{H}{b + p},$$

which is the exact mathematical relation true for all values of *h*.

The change in dimensions of the arms of the pantograph is directly proportional to the elevation *h* of the object, and also to the element *h* discussed above and generated by the footwheel. This proportionality is carried out by proper ratios between pulley diameters. The ratio *R* of the scale change is the photograph scale S' for an object of elevation *h*, divided by the datum scale *S*, since $S' = f/(H - h)$ and $S = f/H$, then $R = (H - h)/H$. This agrees with the idea that the photograph scale for elevated objects is always greater than that for zero or datum elevation, and the photograph image position requires a reduction in scale.

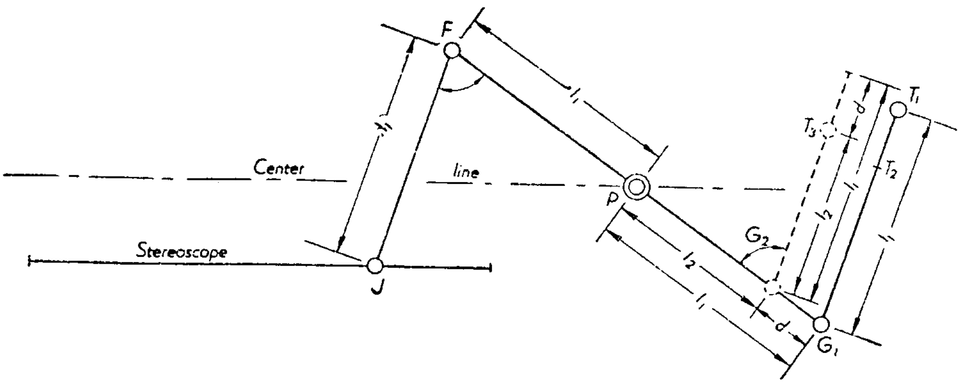

Fig. 3

Figure 3 is a schematic diagram of the stereoscope—pantograph mechanism in which the stereoscope is mounted at J_1, the tracing pencil at T_1, a pivot is maintained at *P*, the arm lengths l_1 of the stereoscope are fixed, the arm lengths of the pantograph are l_1 at 1 : 1 ratio and l_2 for a reduction. A reduction in the scale of motion at T_2 with respect to *J* is obviously the ratio $R = l_2/l_1$ where *R* is the desired scale ratio mentioned above, hence

$$l_2/l_1 = (H - h)/H.$$

The dimension $d = G_1G_2 = T_1T_2$ through which G_1 must move to G_2 and T_1 to T_2 to cause a change in scale is $d = l_1 - l_2$. By substitution for l_2 from the previous equation, $d = hl_1/H$. Thus *d* is directly proportional to *h*. The increment *d* is transmitted to G_1 and T_1 by means of piano wire, steel tapes and pulleys, and the scale change is geometrically correct for all elevation differences.

The increment T_1T_3 is the distance through which the map sheet must be moved so that the pencil point will remain at the same point of map detail. It is directly proportional to the element *h* generated by the footwheel and is also always parallel to the centre line of the plotter. The motion is hence also obtained mechanically with pulley ratios. The proof of the proportionality of T_1T_3 and *h* is obvious from the consideration of similar triangles of fig. 2. In order to prove that T_1T_3 is parallel to the instrument centre line, it is necessary to consider also the motion of the stereoscope *J*, which changes the positions of T_1, and which is moved in accordance with the mental vertical location of the floating mark, as for example, it is made to " climb " a flagpole represented by a distinct line on each photograph, but by merely a single dot on the map. The motion of the pencil point *T1* along the outer arm of the pantograph, through the freely moving elbow *G1*, is such as to constantly maintain an equality between the angle at the elbow *G1* of the pantograph and the angle at the elbow *F* of the stereoscope. This is done by means of a rather ingenious arrangement of piano wire, pulleys, and a differential gear.

The plotter is designed and used principally as a one-man device. The pencil point is raised and lowered by a solenoid operated through a switch located conveniently at the end of an electric cord.

The rotation of the stereoscope eyepieces for operation from either side is quite automatic. Geared rotating dove prisms are employed which retain the proper stereoscopic orientation. There are three adjustments on the stereoscope eyepieces for the comfort of the operator, namely, interocular distance, focus and convergence.

A second plotter is near completion; it differs only in that the stereoscope is stationary and the photographs are moved as a pair with hand wheels somewhat like many European photogrammetric instruments.

CONCLUSION

The plotter has been producing 20-foot contours successfully using 1 : 20 000 scale photographs taken from 13,750 feet. The rate of production has been about 1.25 square miles per man-day. The resulting maps were thoroughly checked by means of vertical accuracy field tests and were well within standard accuracy specifications. The tests indicated that contouring was somewhat better than multiplex work done with six-inch wide angle photographs at 12,000 feet in an adjoining area of similar terrain(4). The multiplex production rate was about 0.7 square miles per man-day.

The system was at its greatest advantage in irregular coastal areas accompanied by bays, inlets, river mouths, and off-lying islands, and where existing horizontal and vertical control is sparse. The photographs possess the further advantage of being of large scale, exhibiting the intricate shoreline pattern with its rocks, etc., whose positions may be used later by the hydrographic party for determining locations of its soundings.

(4) Subsequent multiplex work in this type terrain was accordingly confined to 10,000 feet flying height, which increased the accuracy and yet maintained the former production rate.