OPERATIONS AND COMPARISON OF THE STEREOPLANIGRAPH*

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OUR one Stereoplanigraph has been operated for about 65,000 hours. It has run an average of 16 hours a day for 14 years. We have torn it completely down and reassembled it no less than four times. We converted from a 4-lens camera plate holder to a Metrogon plate holder, and, in so doing, completely redesigned and rebuilt the auxiliary focusing mechanism, both mechanically and optically. We have plotted maps at nearly every scale and contour interval, from vertical photography and obliques and Tri-Metrogon. In short, we have been exposed to the Stereoplanigraph. And we still like it.

This is not going to be a scientific discourse. On the contrary, it is going to be a strictly commonplace discussion of the Stereoplanigraph, as we have found it, without benefit of mathematics. We draw maps with this machine so busily that we rarely have time to conjure with its formulae.

All stereoscopic plotting machines are a compromise. The Stereoplanigraph gains efficiency at the expense of increased complexity. With this increased complexity come problems of maintenance. Without the skills and facilities to readily take care of maintenance, the machine will prove a disappointment. Maintenance is a matter of degree. The Stereoplanigraph takes more than some similar purpose machines and less than others. We believe that, with our facilities and particular set-up, the Stereoplanigraph provides a highly satisfactory production to maintenance ratio.

When in perfect condition and operated by a highly experienced man with ten-second eyes or better, assisted on the table by a trained man, with good photography and ample, well-selected control, the following may be expected from the Stereoplanigraph:

1) It will draw from photographs taken with lenses matched in focal length to $\pm.08$ mm. and to within $\pm.01$ mm. in distortion (referred to the calibrated focal length) to an accuracy of 1/2500 altitude at 90% of the points tested.

2) It will draw satisfactorily up to eight times the negative scale.

3) It will require an average of 2 hours per model to set up.

4) It will draw at an average rate of 2 inches per minute at the negative scale on smooth, fairly straight, not too tightly spaced contours. (Variation with special conditions will be between 1/3 inch and $3\frac{1}{2}$ inches per minute.)

The Stereoplanigraph may be compared with other three dimensional machines in the following respects (by three dimensional we mean machines which effect change of elevation by a change of z rather than by parallax measurement):

(a) The Stereoplanigraph, utilizing the Porro system, reprojects thru identical lenses at infinity focus and brings the image to finite focus in the plane of the floating mark by an *automatic focusing* system interposed between them.

(b) The Stereoplanigraph has a separated base involving 2 floating marks.

(c) The Stereoplanigraph has a separate drawing table with wide ranges of scale.

(d) The Stereoplanigraph operator sees the image under magnification, thru an optical viewing system.

(e) The Stereoplanigraph is operated with hand wheels and a foot disc.

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Making a quick comparison, the Multiplex and the Kelsh Plotter do not use the Porro system, but depend on stopping a projection lens down in order to get depth of focus. They have a compact base projecting the rays to an actual intersection at a single floating mark. They have a fixed ratio of negative to drawing scale. The operator views the projected image on a screen without any optical viewing system and at a fixed magnification. Drawing is accomplished by moving the drawing screen to which the pencil is attached, by hand.

Machines like the Wild A-5 do not reproject the rays of light, but use a mechanical representation of the ray which actuates a scanning system for viewing the picture. Like the Stereoplanigraph, however, they have a separated base, two floating marks, a separate drawing table with scale range and see the picture thru an optical viewing system controllable as to absolute magnification. They operate with hand wheels.

Having now roughly compared some of the three dimensional machines in their optical and mechanical features, let us examine them in the light of what these differences may mean in effective map production.

The clarity with which the operator views the image is a function of definition and magnifications. The Stereoplanigraph and Wild A-5 are "sharp-sighted" machines. The image quality is good and magnification is at optimum value. The Multiplex and Kelsh Plotters have excellent definition only at one elevation, and the definition falls off as the terrain departs from flatness. Their magnification is of a lower order. Thus they are "dull-sighted" instruments. If the operator is also "dull-sighted," this proves no disadvantage, but if the operator is sharp-sighted the pictures may be taken from a higher altitude, especially if the terrain is rugged when plotted in the Stereoplanigraph or Wild A-5.

This discussion might be considered an over-simplification of the problem. Offsetting the sharp-sightedness of the Stereoplanigraph is error introduced by the automatic focusing system, unless it is in absolutely perfect adjustment; and in the case of the Wild A-5 there is a complicated mechanism between the point in space at the foot of the guide rods and the floating dots which are in the observing system. Unless the user has the talents and the facilities for keeping these delicate mechanisms in perfect adjustment, he may be inviting errors much more serious than the "dull-sightedness" of the other type of machine. It is like a good weighing scale versus an assayer's balance. The latter is only better if in perfect adjustment and when equipped with weights in grams and grains. If you use ounce weights it can weigh no closer than ounces. A man with only one-minute eyes using the Stereoplanigraph is using ounce weights on a delicate balance.

The reason the sharp-sighted machine can get better accuracy, in some cases, out of the same picture, is that smaller quantities of vertical parallax are discernible, and therefore the model can be more perfectly adjusted, and is flatter. Thus the Stereoplanigraph, if in perfect adjustment and in the hands of a well qualified and sharp-sighted operator, may achieve higher efficiency.

There are certain advantages in the separated base. It permits an optical viewing system which would otherwise be impractical, and it permits using the pictures at full scale and reprojecting thru identical lens types.

The separate drawing table permits a wide range in the flight-plotting scale ratio. It also results in less interruptions in drawing, as the assistant numbers contours, straightens them out if they become messed up, and checks the completeness of drawing under ample illumination.

The proponents of hand wheel operated machines such as the Stereoplanigraph are just as convinced of their greater speed as ever. This has been quite a controversial subject and the Multiplex and Kelsh proponents can still state that when a map comes off the Stereoplanigraph it isn't finished, and to arrive at a comparable basis all the time photo editing must be taken into consideration. They argue that the capital investment is so high in the Stereoplanigraph that the operator can't afford to hold it idle while he straightens up and puts expression into his work. That, they say, must be left to someone else, and the cost of these people who take the rework where Stereoplanigraph leaves off, equalizes the apparent faster and more efficient plotting of the Stereoplanigraph. This question may still be argued long after we have settled which came first, the chicken or the egg.

Similarly, people have firm opinions as to the merit of handwheel operation. Since there is no agreement as to whether the Stereoplanigraph in total is more efficient, no decision can be reached as to one of its component factors, the hand wheel operation.

Having now stated some of the reasons we believe are responsible for efficient production, let's examine our actual operating techniques. We believe that the first link in the chain of operations is often a weak one. Air camera distortion is not matched closely enough and weakens all systems of mapping. For example, if the taking camera lens has a distortion of 0.12 mm. at 35° from axis, (referred to the calibrated focal length), and the plotting camera has .08 mm., there is a difference of .04 mm. in an azimuth direction of 63° from the picture base. This gives a parallax error of .018 mm. on each picture of the stereoscopic pair (.06 mm. cos 63°). This error is cumulative with a resulting total error of .036 mm. The average base of a stereoscopic pair is 3.6″, or about 91.5 mm., and this quantity divided by .036 mm. shows an error will result of 1/2500 of the base length, which is the same fraction of the altitude. If the system is being used for an accuracy of 1/2500 altitude, for example, there could be a curvature of model equal to the total tolerance. A mean plane which splits this error could vary from the stereoscopic image of a flat surface by plus and minus half of the total tolerance. We are very fortunate to have had a choice from a great many Metrogon lenses, and we have today six air cameras which match our plotting equipment very closely.

Another weak link of our chain is the flatness of the camera platen. Our standard specifications require that it be flat to .0005″, but tests made of the platen do not indicate whether it remains flat when the pressure is applied. We formerly used Fairchild K-17 cameras, until we discovered that the platen deformed as much as .005″ when pressure was applied. This is ten times the amount which our specifications aim to establish. All of our precision cameras in use today employ a heavily ribbed platen which remains flat, within measurable limits, at all times. A deformed platen introduces a very serious error.

A third weak link in our chain is vacuum failure. We have long considered using glass plates in the air camera, but our experience with glass plates used as diapositives indicates that there is perhaps more trouble caused by emulsion creeping or slipping, because of inferior adherence to the glass base, than is caused by vacuum failure and differential shrinkage of the film base. We continue to use plates for our diapositives only because there is no satisfactory way to flatten film in our Stereoplanigraph plate holders without introducting a plate of glass in the optical train, and this of course is impractical. We are giving some preliminary consideration to going back to a film camera with a glass plate focal plane, like many of the models of 20 years ago. Then we would use a glass plate in the Stereoplanigraph plate holders, thus matching and compensating the glass plate of the air camera. Such a move would involve substantially rebuilding of all our air cameras and our Stereoplanigraph plate holders. In the meantime, we are taking every precaution with our vacuum, such as having a gauge on top of the camera right in front of the operator's eyes, and having this gauge read the amount of vacuum on the platen, rather than somewhere along the line.

We use the Fairchild Smith developing and drying machines and we stabilize our film in a humidity controlled room before making our diapositives. We handle the film as little as possible and never at any time touch the emulsion. The diapositives must also be handled with the greatest of care, and even then a substantial number of them have to be remade because parallax indicates an emulsion movement.

The stereoscopic set-up begins by placing the diapositives in the Stereoplanigraph plate holders, using the collimation marks as a quick guide to get the image approximately centered. As far as we are concerned, the collimation marks are a convenience, but not a necessity. Similarly, we use magazine cameras, which are not doweled, and K-17 lens mounting methods which center the lens by pressure from a felt band. Neither we nor Government agencies which have checked our photography for stereoscopic mapping and approved it, have been able to detect any trouble from the non-rigid position of lens, magazine and collimation marks. And since the proof of the pudding is in the eating, and not the recipe, we feel that precision camera specifications could well be reviewed with the thought of placing emphasis at spots where experience has proved it to be most important.

After placing the plates in the Stereoplanigraph a bx setting is made. If, for example, a map is to be drawn at 1:24,000 from photography at 1:60,000, the Stereoplanigraph would be set up at about 2 times the picture base, and 1.25:1 gears would be used between the Stereoplanigraph and the plotting table. In this case a bx would be tentatively set up of about 185 mm. An alternative setup would be a 2.5 base on the Stereoplanigraph and 1:1 gears to the table. In this case, the base would be set to begin with at about 230 mm. The base may be set up on either side of the machine, or part on each side. In case of short bases it makes no difference. If the base is long it must be split, as there is insufficient capacity on one side. From here on the stereoscopic model is set up in the conventional manner. In fifteen minutes or half an hour, the stereoscopic model is set up equivalent, perhaps, to the best setup obtainable with a dull-sighted machine, and from here on, for about an hour or more, the operator is "chasing" the quarter dots of parallax from corner to corner until he can do no better. He then for the first time connects the plotting table. He sets the mark on one control point, and the pencil on the corresponding map point and then clamps the x and y drive clutches. He then runs to another control point. He probably misses it in both distance and azimuth. The assistant sets a microscope on the first point and rotates the map sheet around this point to correct the azimuth. He then makes a measurement of the distance error and calculates a percentage of the total. The bx is increased or decreased by this percentage, and the scale should now be very close to right, requiring only a touch more, perhaps, as other control and passpoints are checked. At the original point the elevation counter was also set. This reads in millimeters. If the Stereoplanigraph is set up at 1:24,000 and the elevation of the initial point is 1,487 feet, the counter setting is calculated as follows:

$$\frac{1487 \times 304.801}{24{,}000} = 18.89 \text{ mm.}$$

As the horizontal position of the various points is checked, their elevation is also read. If the horizontal position is close and the elevation is off, the operator makes a good guess based on his years of experience of how much common tip and common tilt are required to horizontalize the model. He makes these settings in about 1 minute and then rechecks vertical and horizontal readings. Perhaps a touch of *bx* is indicated and a trifling change in horizontalizing. If now any point fails to check properly, the operator again runs over his model to see if any parallax developed in the horizontalizing. If there is still trouble (there shouldn't be), a systematic check begins of plotting, calculating the control and identification of the image of the control point.

When all the control hits within tolerance, the contour connections with adjacent models are checked, and if these are within tolerance, the model is ready to draw. The planimetry is generally drawn first, although the sequence of operations may vary from job to job. At 1:24,000, roads are indicated by center lines and buildings as dots, which the assistant designates with appropriate symbol. Contours are drawn in both directions, and the assistant checks off each hill top and nose after it has been inspected for any additional contours. The checking system for tops and depression contours and planimetry omissions is a very important factor in production output and completeness of the map. Fifth contours, or fourth, as the case may be, are drawn with a softer pencil to make them blacker, and contours are numbered. In case of messing up in heavy timber or bad shadows, the assistant keeps the contours untangled.

At the end of drawing, pass points are established to help set up the next model. One plate is then removed, *bx* is reversed for the psuedo model, the optical switch is turned so that the opposite eye looks at the retained plate, and the new plate is installed. The stereoscopic model is next set up, and all adjustments are made on the new plate, to bring it into correspondence with the retained plate. After the stereoscopic model is perfected, the scale is set, and only a touch of horizontalization should be necessary, as the retained plate remained in its horizontalized position, and the new plate was adjusted to it.

The map sheet, when completely drawn by the Stereoplanigraph, next goes to Photo-editing. This is a group of topographers who give the map proper expression, and inspect it carefully for form and completeness and add the land net. The names are put on an overlay as a guide to the draftsman who applies the final name as stickup lettering. After photo-editing, the map goes to Drafting where literal inking is performed, or color separation drawings prepared, as the case may be.

The finished map now goes to final editing for inspection before it is delivered.

A job now being drawn by us consists of 7,820 square miles of the heart of the Rocky Mountains in Montana. The map is being drawn at 1:24,000 with 20′ contours. The production through the plotting machines has been at the rate of 1.33 square miles per hour. For each hour of machine work there are 4.65 hours of machine operators' time, plus photo-editing time.

This map is strictly in conformance with U.S.G.S. standards and these figures are a fair criteria of what we are able to produce with the Stereoplanigraph.

While we would be first to acknowledge the advantages of other machines such as the Multiplex and Kelsh Plotter for various purposes, and for operating under various conditions, we are convinced that for our particular purposes and operating conditions, the Stereoplanigraph type of equipment is best for us.