# THE APPLICATION OF STEREOSCOPIC PHOTOGRAPHY TO MAPPING: *A paper read at the Afternoon Meeting of the Society, 11 November 1929, by*

CAPTAIN M. HOTINE, R.E., Geographical Section, General Staff

THE surveying camera is really an instantaneous, yet fairly accurate, theodolite. A single photograph exposed in it will do no more than provide a rapid record of angles which could be measured from the camera station. If the photograph is exposed in a vertical plane, then it becomes an easy matter to derive horizontal and vertical angles from it by measurements on the plate or by simple graphical constructions. This, then, constitutes the first and most direct method of photographic survey which is still used with advantage for small-scale work in the mountains of British Columbia. Photographs are exposed at 1 and 2 (Fig. 1) from the ends of a long base and are used to intersect the position, and determine the height, of detail appearing on both photographs.

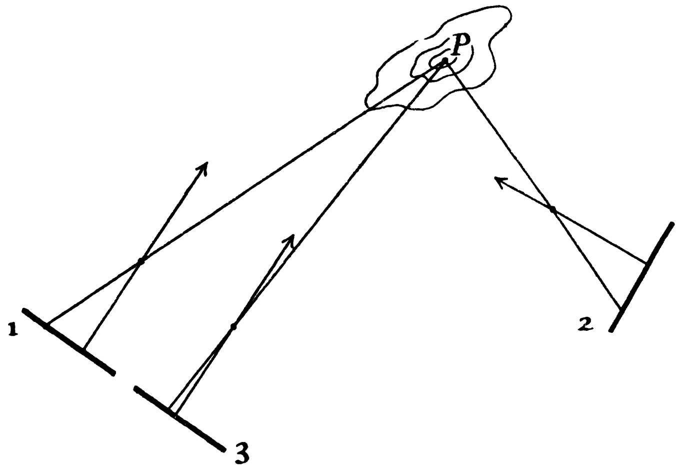


*Fig. 1. Direct method of photographic survey*

The main trouble in this class of work is that the same object P may have an entirely different appearance on each of the widely dissimilar views, and it becomes easy to intersect the wrong point or to provide an inaccurate fixation of the right point. The difficulty may be overcome by exposing photographs at 1 and 3, from the ends of a short base, but in that case we should obtain a narrow angle intersection which is the bane of all good graphical surveyors. To overcome this further difficulty, graphical methods were given up in favour of precise micrometric measurements on the photographic plates, coupled with the stereoscopic examination of the photographs in order that corresponding images might be identified with certainty. The stereoscope is in this case merely a convenient means of seeing two things at once, and has no particular magic of its own.

If we continue to expose the photographs in vertical planes, then we shall retain that facility for the simple determination of horizontal and vertical directions from either camera station. If we go farther and expose the two photographs in the same vertical plane, then it becomes a simple matter to convert stereoscopic measurements on the photographs into horizontal distances from the base line, and thus provide a complete fixation. Full details of this system have been printed from time to time—for example, in an article by Lieutenant (later Brigadier-General) F. V. Thompson on "Stereo-photo Surveying" in the *Geographical Journal* (31, 534, May 1908)—and it is not proposed to repeat them here. The general principle on which the measurement rests is illustrated by Fig. 2. Any natural object will give rise at exposure to corresponding images *o* and *o′* on photographs *P* and *P′* taken from the ends of the base *EE′*. During stereoscopic examination, the photographs may be viewed from *E* and *E′* in such a manner that only one picture is presented to each eye. The stereoscopically fused image of the original natural object will then appear to lie at *O*. A pair of artificial "floating marks" *ff′*, in optical contact with the photographs, will similarly give rise to a stereoscopically fused image at *F*. By moving *o* or *f* in the plane of the diagram the relative distances of *O* and *F* from the eyes can be varied. The amount of this motion to produce apparent equality in distance between *O* and *F*—which occurs when *oo′*=*ff′*—is measured micrometrically and is used in a simple formula to determine the corresponding distance in Nature. This simple discussion is open to several more or less academic objections, but it will suffice for a condensed practical explanation. A full account of the subject will be found in Professional Paper No. 4 of the Air Survey Committee, although even that is not entirely free from academic objection. This system was first applied practically in Fourcade's Stereocomparator (Pl. 1) about 1900. The widespread belief that Pulfrich of Zeiss was first in the field is entirely due to the fact that Mr. Fourcade was and still is modest about his achievement. Reference should be made to Mr. Fourcade's own description of the construction and use of this instrument in the *Transactions of the Royal Society of South Africa* (vol. 14, 1926, p. 83). It might still be used with advantage for small-scale surveys of mountainous country, where the main requirement is a framework of point fixings on which to hang intermediate sketching, and which could not pay the overhead costs of modern automatic machines.

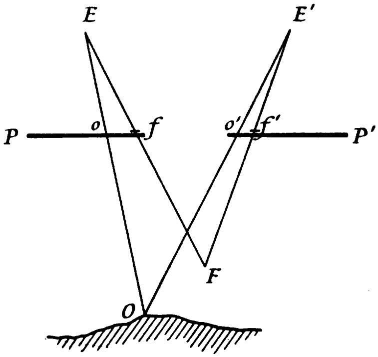


*Fig. 2. Stereographic survey*

In order to secure as much ground as possible on a pair of photographs, it was later found desirable to give up the restriction to exposure in the same vertical plane and to expose the photographs on tilted and converging orientations. At the same time, attempts were made to avoid the labour and possible mistakes involved in any system of point-by-point plotting and to substitute some means of automatically plotting plans and contours from the perspective stereoscopic view. These attempts have led to the evolution of such machines as the Thompson Stereoplotter, the Von Orel Stereoautograph, the Hugershoff Autocartograph, the Wild Autograph, which have been described from time to time in the Society's *Journal.* The first machine of this type (Fig. 3) is due to Deville, the late Surveyor-General of Canada. The photographs were viewed by reflection at the surfaces of two half-silvered mirrors under such conditions of distance and position relative to the eyes as would serve to re-establish the internal perspective of the field camera. The photographs and mirrors were further adjusted to reproduce the external orientation of the two views, when a virtual true-to-scale stereoscopic image of the landscape could be seen, apparently behind the mirrors. A "floating mark" consisting of an adjustable target carried on a movable vertical column could be moved about in this virtual image in apparent coincidence with various natural features. A pencil at the base of the column plotted the position of such a natural feature, while the height of the target above the plotting board furnished a measure of relative altitude. For pure simplicity this arrangement has never been surpassed, but unfortunately it has certain optical and mechanical disadvantages which decided the inventor against its full development. It is interesting to note that the same principle of a real "floating mark" has been used in at least two modern machines.

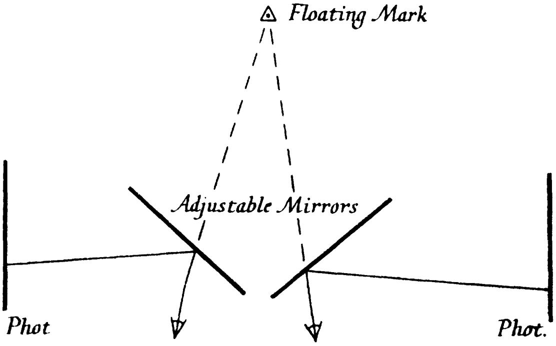


*Fig. 3. Deville's Stereoscopic Plotter*

The last machine of this type is that finished piece of intricate workmanship known as the Wild Autograph (see *G.J.*, 70, 358, October 1927), which provides a complete, if complicated, answer to any orientation or tilt whatsoever of the camera during exposure, provided such exposure conditions are measured on the ground or can be subsequently determined. It is used extensively for ground surveys in mountainous regions, and is probably an economic proposition on medium or large scales. There is little doubt about the excellence of the maps produced under these conditions. Even in mountainous country consisting of well-defined steep ridges, as opposed to broken country, certain areas of dead ground appear on the ground views, but no difficulty is experienced in filling these by the plane-table.

This stage of development has by no means been neglected in this country. Messrs. Barr & Stroud have produced a Photogrammetric Plotter which is superior in general conception and practical simplicity to any Continental model. Like all first models, it contains certain mechanical defects which can easily be remedied in subsequent instruments.

The introduction of photography from the air has considerably extended the possible applications of photographic surveys by providing suitable views of flat or undulating country, with the further advantage that longer bases are usually possible than in the case of ground stereographic surveys. It has, however, introduced the problem of unknown exposure conditions, for whereas the position, tilt, and orientation of a photograph exposed deliberately on the ground can easily be measured directly, none of these quantities has so far been obtained directly in the case of air photographs. The aeroplane travels so fast that its position cannot be established to any useful degree of approximation, while random accelerations preclude a determination of level closer than a few degrees. Most of the machines mentioned above were designed on the assumption that the exposure conditions were obtainable by direct measurement, and they consequently depended on this facility for rapid and economic setting of the photographs, in their correct positions for plotting. Whole-hearted, if perhaps misguided, efforts have subsequently been made to adapt them to the case of unknown exposure conditions. The conditions are however so entirely different from those obtaining in the case of ground photographs that it is safe to say, in the light of after knowledge, that the whole question should have been tackled afresh.

An individual air photograph, or an individual stereoscopic pair of air photographs, requires some form of surveyed ground control in order to establish these exposure conditions. Failing direct measurement in the air, which is not likely to be realized with sufficient accuracy for many purposes, there is no alternative. Originally attempts were made, notably by Professor Hugershoff, to establish the exposure conditions of single photographs from ground control by calculation. Such methods have been considerably shortened in this country by Captain McCaw, but even so, no economically practicable system of computation has been evolved. Linear and angular dimensions are so hopelessly intermingled in this problem that a simple solution is never likely to be discovered. The difficulty has been overcome in an instrument invented by Lieut.-Colonel (now Colonel) MacLeod known as the "Tilt Finder" and constructed by Messrs. Barr & Stroud, as a means of providing the setting data for their Photogrammetric Plotter. The experimental model of this instrument contains certain optical defects which limit its accuracy to about 15 minutes of tilt, but it is reasonable to suppose that these could be eliminated in subsequent design. A more promising field than the treatment of single photographs has however opened recently, and further development of the instrument is consequently in abeyance.

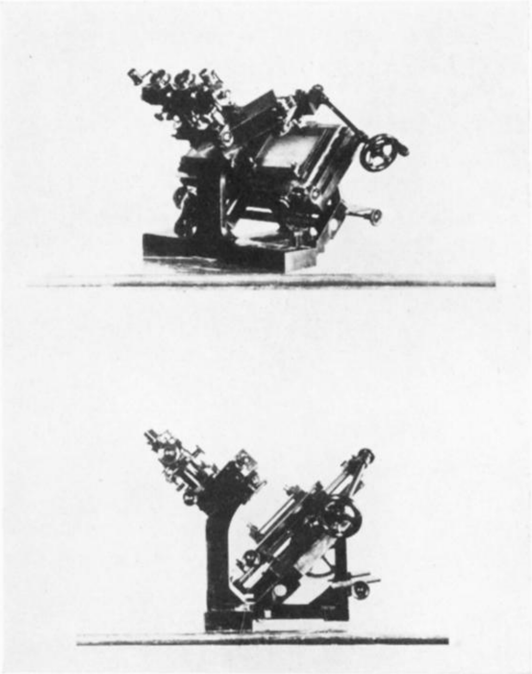
The usual system of setting now practised is to set a stereoscopic pair simultaneously, using the principle of "correspondence setting" originally devised by Mr. Fourcade about 1925. The photographs are first set relatively "in correspondence," which simply implies that the visual directions to corresponding points of photographic detail shall intersect in single image points to produce a true stereoscopic image of the landscape. This operation requires no ground control. Secondly, both photographs are moved together in order to establish the scale and level of the stereoscopic image from ground control.

We shall see later how Mr. Fourcade himself applies this principle. For the moment it will suffice to say that the movements of all Continental machines are not suited to the application of this new method of setting. The first operation of correspondence setting can usually be performed reasonably quickly and accurately, but the subsequent settings for scale and level destroy the initial correspondence setting, with the result that the whole operation has to be repeated by trial and error. A good final result can undoubtedly be obtained, but hardly at an economic speed.

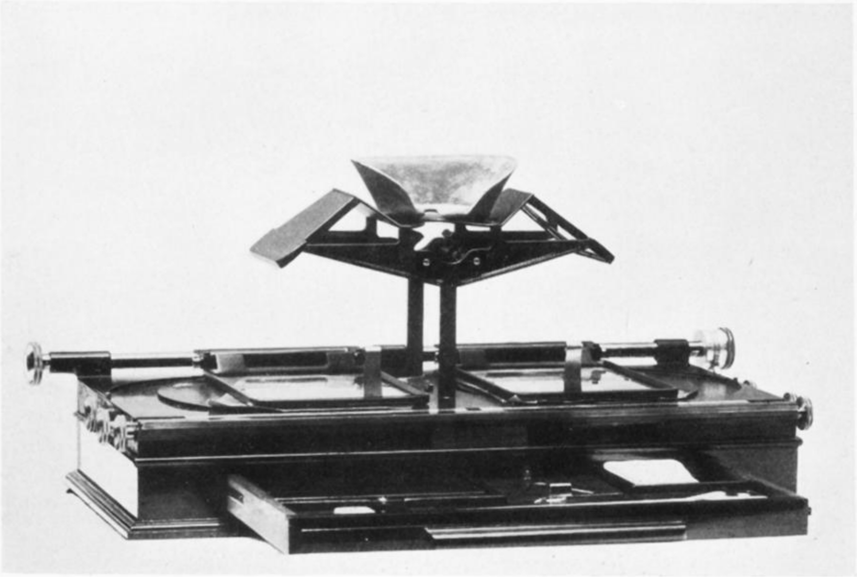
The modification of Continental machines to deal with the setting of air photographs has led to a good deal of instrumental "patchwork." The most notable example is the Wild Autograph, in which an additional movement is now employed. This machine produces excellent 6-inch maps from air photographs, at the rate of 1 sq. mile in 16 hours. Using a somewhat different principle, Mr. Brock, of the firm of Brock & Weymouth, Philadelphia, has devised a modified method of using the original stereocomparator with vertical air photographs. Here again excellent maps are produced, but four hours are consumed in the tilt correction of one pair of plates. The complexity of these modified ground machines, and the time required for setting air photographs in them, mean that they cannot economically be used for air surveys on topographic scales. In addition they mostly require a dense ground control, which adds very considerably to the cost.

Concurrently with such instrumental methods, various simple and wilfully approximate methods of dealing with vertical air photographs have been evolved in order to solve the problem of topographic scales. We have, for instance, the "mosaic" or composite photograph obtained by sticking individual prints together on a common base. In the hands of enthusiasts this "mosaic" idea has from time to time been the subject of gross exaggeration and over-statement, with the result that it is looked on by many surveyors with far more distrust than it actually deserves. The truth is that it furnishes a rapid means of obtaining a very detailed picture of an area of flat country, which may often be used as material for topographic mapping not requiring a greater degree of accuracy in the measurement of short distances than 2 or 3 per cent. In undulating country it is less valuable—on account of the differences in scale occurring at different levels—while in hilly country it cannot be compiled at all. I have, indeed, recently seen a "precise mosaic" of part of the American Rockies, obtained by cutting out portions of the photographs at the same contour level, subjecting these portions to an individual degree of enlargement, and assembling in much the same manner as a relief map. Apart from the prohibitive amount of time required to compile such a mosaic, a knowledge of the relief has to be acquired which in that type of country amounts almost to complete mapping. It is interesting, but can hardly be considered a serious contribution to economic mapping.

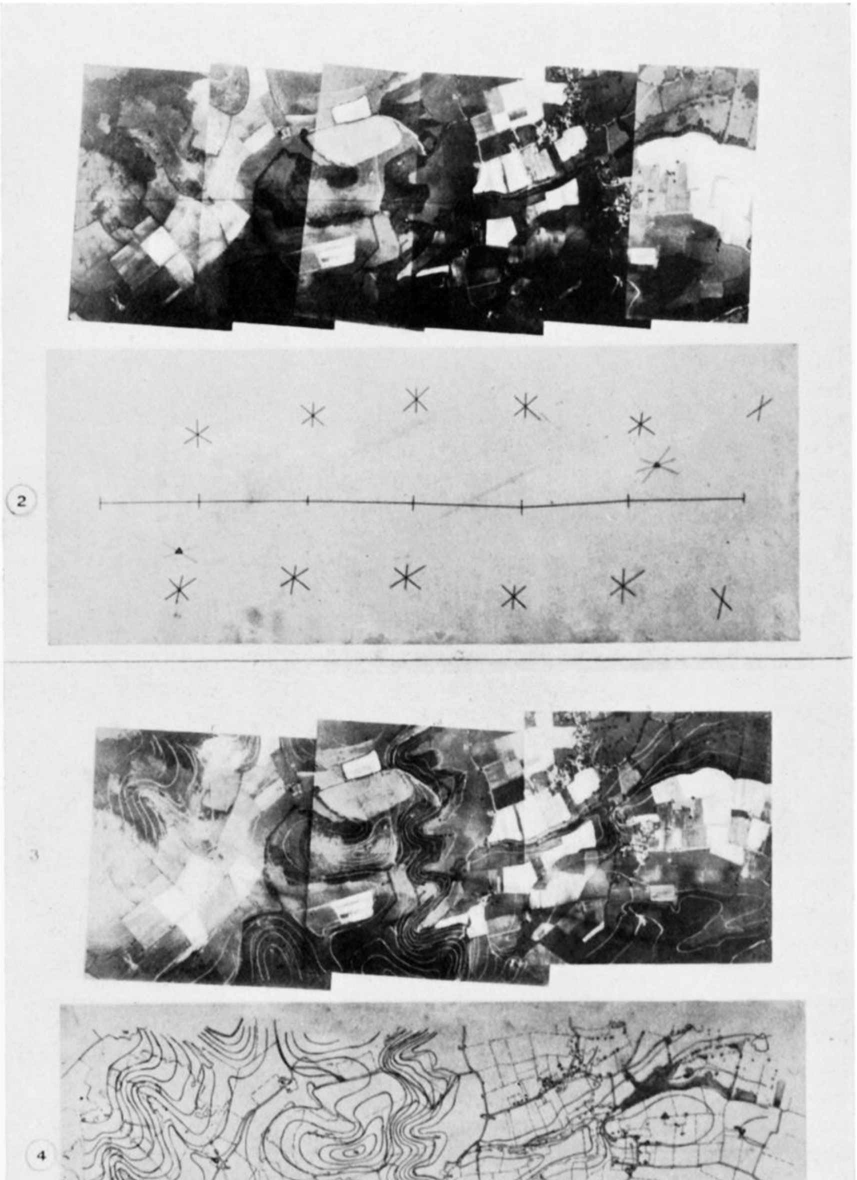
While still retaining the merit of simplicity, we can improve very considerably on the mosaic by graphical plotting and by simple stereoscopic interpolation of heights and contours between a network of control heights fixed on the ground. Such a method has perhaps been developed in greater detail in this country than in any other, although the principles on which it rests are age-old. There is, indeed, some doubt as to whether the credit should be given to the



1. *Fourcade's Stereocomparator*



2. *Barr and Stroud Topographical Stereoscope*



*3. Experimental Survey: Arundel Method* inventor of the plane-table, whoever that was, or to a gentleman in the United States who dealt in photographs taken from balloons about 1898. We call this the "Arundel" method because it was first put into practice in this country in an experimental area near Arundel. Part of this experimental survey is illustrated in Pl. 3 in the various stages of blank photographs, control plotting, contoured photographs and finished map. The only instrument used in present practice is the Topographical Stereoscope constructed by Messrs. Barr & Stroud and illustrated in Pl. 2.

The Arundel method produces excellent topographical maps rapidly and cheaply, but in its simplest form its application is restricted to country varying in relief by not more than 10 per cent. of the altitude of flight. It also requires a network of ground heights—something like 4 or 5 per square mile—and fixed positions every 5 to 10 miles. Good draughtsmanship is essential for the purely graphical plotting, although this can be replaced by a simple extension employing a little computation. Under these conditions, the method will continue to be used in spite of any foreseen future development. The burning questions of time and money will always ensure that no more complicated method is used than the scale and purpose of the survey warrant.

An attempt has recently been made to avoid the restriction imposed on permissible relief of the ground by obtaining the tilt of each photograph from a form of computation based on Fourcade's correspondence principle. No additional ground control is required, but the time of plotting is increased by half an hour to an hour per photograph. This method also takes its name from the location of the experimental survey near Clova in the Eastern Highlands of Scotland. So far as results are concerned this experimental survey was entirely successful. Unfortunately, the method is rather too complicated for routine work in large areas. The same process will probably be simplified and quickened by using the Fourcade Stereogoniometer (described below) or by developments in air navigation tending to more stabilized flying. Gyroscopically controlled aircraft may, for instance, make it possible to limit the determination of tilt to, say, every tenth picture.

Full details of the Arundel and Clova methods will be found in Professional Papers Nos. 3, 4 and 6 of the Air Survey Committee.

To overcome the limitations of the Arundel method on topographic scales, as regards relief and close height control, as well as to provide a ready means of tackling larger scales, the tendency is to employ a machine, but a machine designed expressly for the unknown exposure conditions obtaining in the case of air photographs. I refer to the Fourcade Stereogoniometer, which is shown diagrammatically in Fig. 4. Essentially, the machine consists of a pair of cameras $CC'$ in whose focal planes are placed the photographs under examination. The position of the photographs, and the lenses of the two cameras, can be adjusted to correspond with the camera in which the photographs were originally exposed. The photographs are observed through a fixed binocular telescope system $T$ provided with floating marks, the sighting rays being reflected into the camera objectives by two plane mirrors $M$ and $M'$.

In order that different parts of the photographic field in a vertical direction may be brought under examination, both cameras may be swung *together* about a horizontal axis $PP'$, which represents the base line joining the two camera stations. To bring different parts of the field in a horizontal direction under examination the mirror carriers are movable together in a direction parallel to *PP'*. At the same time the mirrors themselves are automatically rotated about vertical axes by the amount necessary to ensure that the perspective ray to the point sighted is reflected along the fixed line of collimation of the telescope (see the dotted position of the mirrors in Fig. 4). To vary the convergence of the sighting rays, and thus alter the apparent stereoscopic depth of the photographic image in relation to the floating marks, provision is made for a similar movement of the right-hand mirror only.

In addition to these three observation movements, five setting movements are provided in order to bring the two photographs into correspondence, as defined above, and thus into their correct positions relative to one another and to the base line. These movements are indicated on Fig. 4 by arrows. The first model of the instrument is shown in Pl. 4. A new model is now being designed by Mr. Fourcade with an automatic plotting mechanism which is coupled to the observation movements.

There are four main points about this instrument to which I should like to call your particular attention. The first is that the correspondence setting movements are made in respect to the base line, to which they are properly related, and not, as in all Continental machines, to the horizontal. The result is a quicker and more accurate relative setting in cases where the base line is inclined to the horizontal. The second is that the observation, or plotting, movements are entirely distinct from the setting movements and have no effect on the previously established correspondence of the photographs. The result is that both trial and error are reduced to a minimum. The third is that no hard-and-fast type of ground control is required. Depending on the scale and purpose of the survey, the control may vary from a base length and two angles of elevation or depression on each pair of photographs, to a similar amount of control at each end of a strip of photographs; from an ordinary triangulation, to a simple record of altitudes measured in the air. The fourth is that the use of the instrument may vary from the determination of tilts and spot heights for rapid detail plotting by the Arundel method to automatic plotting for more deliberate or larger scale surveys. These considerations would appear to indicate a wider field of practical application than has hitherto been possible with the Continental machines.

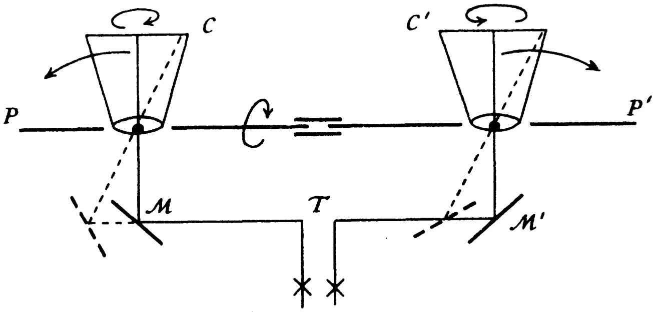


*Fig. 4. Principle of the Fourcade Stereogoniometer*

## THE BARR AND STROUD PHOTOGRAMMETRIC PLOTTER

In the course of the preceding paper I remarked that the Barr and Stroud Photogrammetric Plotter was "superior in conception and practical simplicity" to any Continental machine designed for the same purpose. During the subsequent discussion this statement was received with some scepticism, due perhaps to an undue British reticence. The Barr and Stroud machine has not yet been described, but if silence is being taken as a sign of failure, then it is indeed time for this defect to be remedied. Professor Barr, the designer of the machine, could have written a far better description, and I asked him if he would consent to do so. In a way I am glad that he refused. My own efforts will be less hampered by the modesty pertaining to and becoming the designer himself.

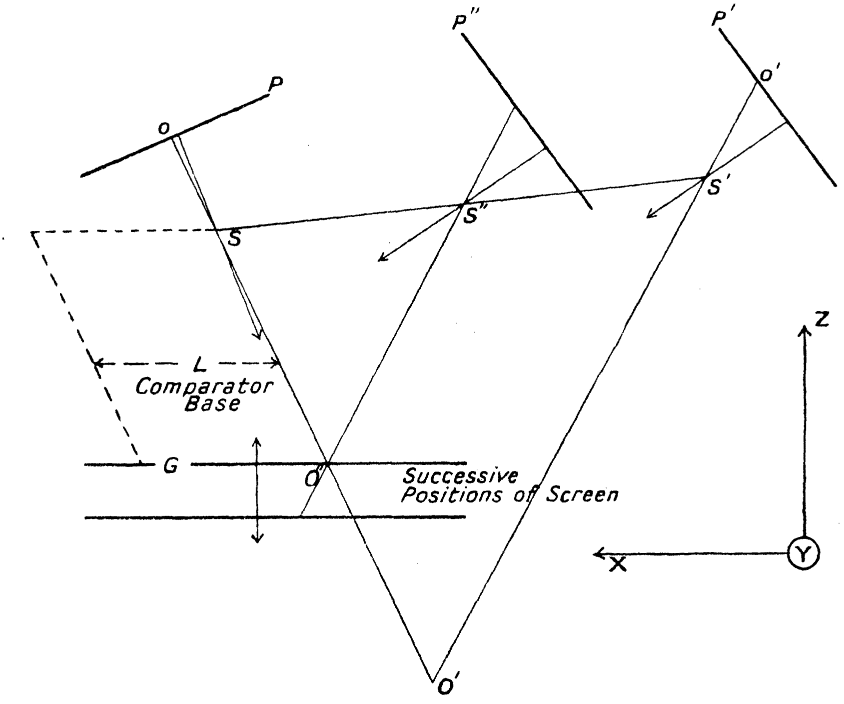


*Fig. 5. Geometry of the Photogrammetric Plotter*

### *Geometrical Principles and Plotting Movements*

Imagine a pair of air photographs $P, P'$ (Fig. 5) exposed at the ends of a base $SS'$ and covering, in whole or in part, the same area of country. If the plates were taken out, developed and put back in their original positions in the cameras—which for the moment are assumed not to have been moved—then it is clear that light-rays originating in corresponding image points $o, o'$ on the photographs and passing through the camera lenses would intersect in the position of the natural object $O'$ which gave rise originally to such corresponding images. Theoretically, at any rate, this would provide a means of "reconstructing" the original landscape to its natural scale.

Instead of keeping the cameras immovable between exposure and reconstruction, suppose that we move $S'P'$ always parallel to itself and in the direction of the base-line $SS'$ until it takes up a position $S''P''$. The reconstructed landscape (of which $O''$ is one point) will now be similar in all respects to the original landscape, but reduced in all linear dimensions in the ratio $SS''/SS'$. A little consideration will show that this must be so, without the necessity for a mathematical proof.

Suppose that we take a screen $G$ to represent a horizontal plane in Nature and arrange to give it a single movement perpendicular to its plane, that is, in the vertical direction in Nature. When the two corresponding images caught on this screen coincide in a single point $O''$, then the position of $O''$ on the screen will provide its plan position in relation to the position of the base-line $SS''$. If the rays originally came from a point at a higher level than $O'$, the screen $G$ would have to be moved higher in order that the two rays might meet on the plane of the screen. Movements of the screen for various points on the ground therefore give a measure of the relative levels of these points.

Equally well, we may keep the screen fixed and bring the two corresponding images into coincidence at $O''$ by moving both cameras together in a direction at right angles to the screen. The amount of this movement of the cameras (known as the Z-motion) will now furnish a measure of vertical heights. It will be evident that all points on the ground at the same level as $O'$ will have their two projected images coincident on the screen, and the plan positions on the screen of these images will correspond to the plan positions of the original points on the ground. When the level of the screen, or the distance from it of the cameras, is altered to bring a fresh set of points into coincidence, the plan positions of these other images will as before correspond to the plan positions of the original points on the ground. A pencil moving over a drawing-board in such a manner that its movements are always equal and parallel to corresponding distances between coincident screen images will plot the plan positions of these screen images.

As a further possibility, we may provide two more movements for the cameras and thereby bring corresponding screen images into coincidence with a particular point on the fixed screen. These movements, which are both parallel to the plane of the screen and, for convenience, are arranged in directions at right angles to one another, provide a means of establishing the relative plan co-ordinates of such points as $O''$. If these movements, known as the X- and Y-motions, are imported by direct gearing to the drawing-board, then the pencil, which is now considered fixed, will automatically plot plan positions.

Either of the methods described in the last two paragraphs may be employed for plotting plan positions. Actually, both methods are used in a manner which will appear later.

Before plotting, we have seen that the photographs have first to be replaced in projection cameras geometrically similar to the field cameras. These projection cameras are provided with certain setting movements in order that they may occupy the same positions relative to the machine base-line ($SS''$ in Fig. 5) and to the plane of the screen as the original field cameras occupied relative to the field base (*SS′* in Fig. 5) and to the horizontal plane in Nature. By means of the plotting movements described above we are then able to derive a correct plan of the landscape and also a measure of relative heights. The scale of the resulting map, in all three dimensions, will be $SS''/SS'$.

If the photographs had been exposed on the ground instead of in the air, in such a manner that they occupied planes more nearly vertical than horizontal, then we consider the plane of the screen to represent a vertical plane in Nature. In that case, the Z-motion of the machine affords a measure of horizontal distances, and the Y-motion affords a measure of heights. If the X- and Z-motions are now coupled to the drawing-board—instead of the X- and Y-motions—we are still able to draw direct plans. By this means the machine is made capable of dealing with photographs at any inclination whatsoever.

In one respect only does the geometry of the actual machine depart from the foregoing simple description. The two projectors are separated in the X-direction by an arbitrary amount *L* from the theoretical positions *SS″* of Fig. 5. The two screen images are then no longer observed in actual coincidence but are considered as coincident—for the purpose of plotting—when they fall at the same distance (*L*) apart as the projectors have been separated. The increased separation *L* is known as the "comparator base." This device is employed also in most Continental machines. Mechanically it provides more room for the projectors, and optically it enables the two views to be examined stereoscopically without the necessity for first disentangling the images of the two pictures.

### *Optical Principles*

For the internal perspectives of the two photographs to be correctly re-established, we have seen that each photograph must be placed in the focal plane of a projector equipped with a lens similar to that of the field camera. The emergent beam from the projector lens will thus consist of parallel light which would only form a sharp image at infinity. To bring this beam to a focus on the screen a system of auxiliary lenses is employed (see Fig. 6, which represents a side elevation).

In order that the geometry of the machine shall be unaffected by the introduction of this auxiliary lens system, it is necessary for the axis of the latter to coincide in all positions with the line joining the screen image *O″*, of the point under observation, to the front nodal point *S″* of the projector lens. (*O″* and *S″* have been lettered to correspond in Figs. 5 and 6.) It will be seen later that an approximation is made in this respect when plotting is carried out over limited areas without moving the projectors in X and Y. It remains true, however, to say that the axis of the auxiliary lens system passes through the mean point of observation and through the front nodal point of the projector lens. This condition is ensured in the following manner (see Fig. 6). The auxiliary lens system is given three motions of translation similar to the three co-ordinate motions of the corresponding projector; the girder *1* carrying the auxiliary lenses moves bodily in the Y and Z directions, while the lens system moves along this girder in the X direction. The auxiliary lens system is carried on two gimbal axes *2–3* and *4*, intersecting in the point *4* on the axis of the auxiliary lens system. By initial adjustment of the X, Y and Z motions of the auxiliary lens

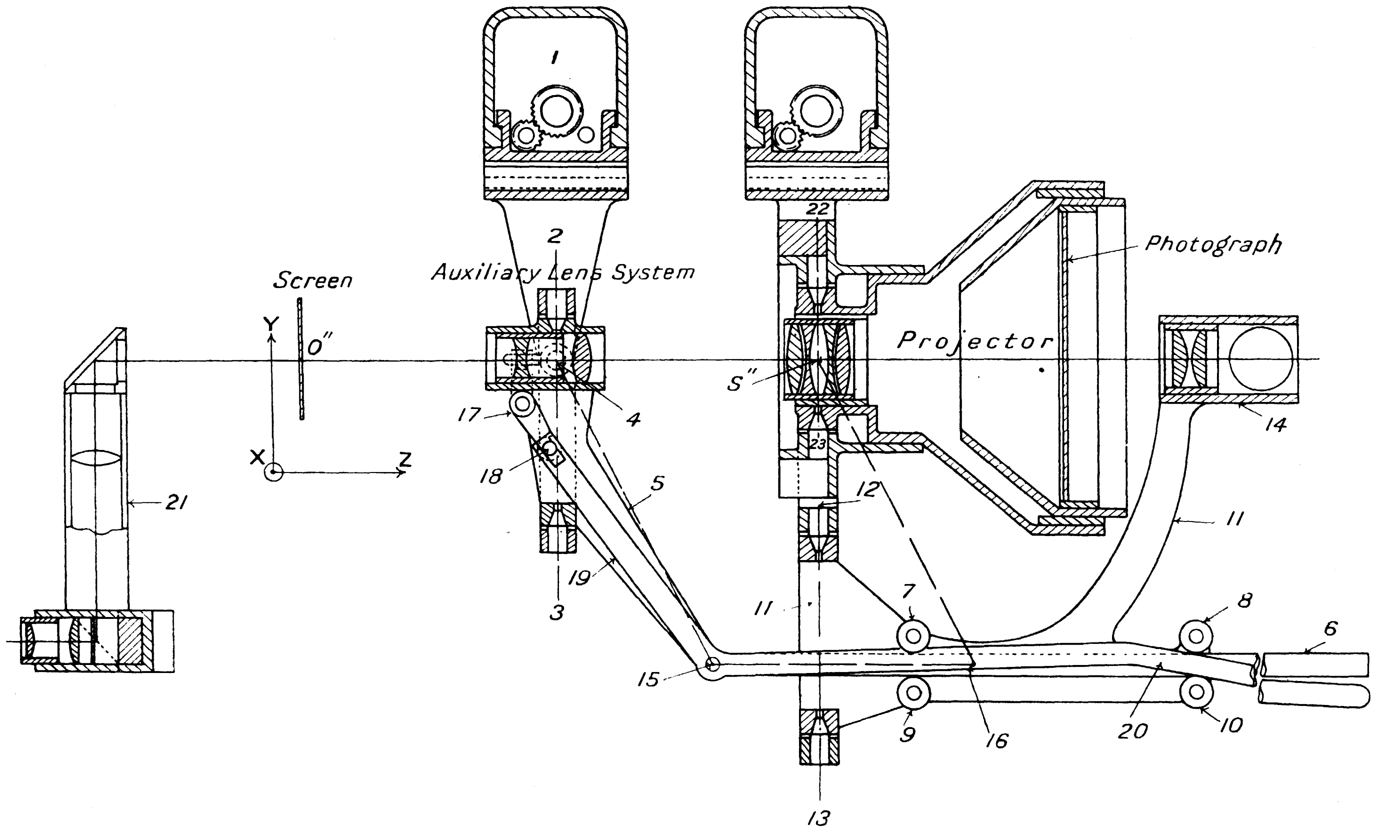


Fig. 6. Construction of the Barr and Stroud Photogrammetric Plotter

system the point *4* is brought on to the line *S''O''* at a point midway between *S''* and *O''*. Thereafter this relative position is maintained by imparting half the X, Y and Z motions of the projector to the corresponding movements of the auxiliary lens system. These movements of the auxiliary lens system are provided automatically through reduction gearing from the X, Y and Z controls of the projector movements.

This arrangement ensures that one particular point on the axis of the auxiliary lens system always falls on the geometrical line of sight *O''S''*. It remains necessary to rotate the axis of the auxiliary lens system about this point until it passes through the front nodal point of the projector lens, and thereafter to preserve this condition automatically for all movements of the latter. This is done by means of the arm *5*, which is rigidly coupled to the auxiliary lens system and is continued as the rod *6*. The latter slides between rollers *7*, *8*, *9* and *10*, which are fixed to the bracket *11*, carrying gimbal axes—of which *12–13* is one —intersecting in the front nodal point (*S''*) of the projector lens. Initially the centre line of the rod *6* is arranged parallel to *O''S''*.

Mechanically, this linkage is equivalent to a single rod rigidly connected to the auxiliary lens system and sliding in a sleeve universally jointed to S''. Its action may be explained alternatively as follows: Suppose that *15* is a point on the centre line of the rod *6* at its junction with the arm *5*. Imagine a point *16* on the centre line of *6* and rigidly associated with the frame *11* in such a manner that *S''–16* is equal and parallel to *4–15*. These two lengths clearly remain equal after any movement whatsoever of the projector or the auxiliary lens system. Moreover, since the angles *S''–16–15* and *4–15–16* always remain fixed in magnitude, *S''–16* and *4–15* are always parallel. Consequently, *15–16* is always equal and parallel to *4–S''*. Any rotation of the line of sight *4–S''* is thus equal to the resulting rotation of the rod *6*, which is imparted through the rigid joint *15* to the axis of the auxiliary lens system.

The bracket *11* carries a condenser and lamp *14*, whose centres are initially adjusted on a continuation of the sighting ray *O''S''*. By means of the mechanism described, the centres of the condenser and lamp remain on the sighting ray *O''S''* for all related movements of the projector and auxiliary lens system, and thus constantly illuminate the photographs in the areas under examination.

It may be admitted here and now that the mechanism described above and illustrated in Fig. 6 introduces errors, particularly in the Y direction, owing to faulty balancing. These errors do not seriously affect plan positions, as plotted, but they are too great to allow the machine to be used for setting the photographs in the machine itself on the Fourcade correspondence principle. Such an application was not, however, considered in the initial design, and the defect could easily be eliminated in subsequent models. Photographs are set in the first model from data acquired in a separate instrument—either from individual photographs in the MacLeod Tilt-Finder or from stereoscopic pairs in the Fourcade Stereogoniometer. These data are provided in both cases by marking the actual plumb points on the photographs and by recording the length and inclination of the base. But for this (avoidable) source of error in the Y-direction, the machine itself could be used for correspondence setting quite as well as any Continental machine.

It remains desirable to vary the focal length of the auxiliary lens system in order that focus on the screen may be preserved for all variations in the distance $O''S''$ (or $O''$–*4*) consequent on the X, Y and Z motions of the projector. This is done by mounting the double convex component in a separate barrel provided with pins engaging in a slotted lever pivoted at *17*. The lower end of this slotted lever is provided with a pin *18* moving in a slot at the end of the lever *19*. The latter is pivoted at *15*, whence it is continued as the curved arm *20* passing over a fixed roller in front of *10*. The under side of *20* is given a definite shape which regulates its rise and fall as the distance between the projector and auxiliary lens system is varied. By means of the lever system described above, the rise and fall of *20* is transformed into an alteration of the separation between the two components of the auxiliary lens system, with an attendant variation in the focal length of the combination.

The two screen images are observed by means of a stereoscopic comparator *21*, provided with floating marks. The apparent separation of the floating marks on the screen is made equal to the "comparator base" as described above. Alternatively, the stereoscopic comparator may be replaced by a coincidence comparator in which comparison between halved images is made on the principle of the ordinary Barr and Stroud coincidence rangefinder.

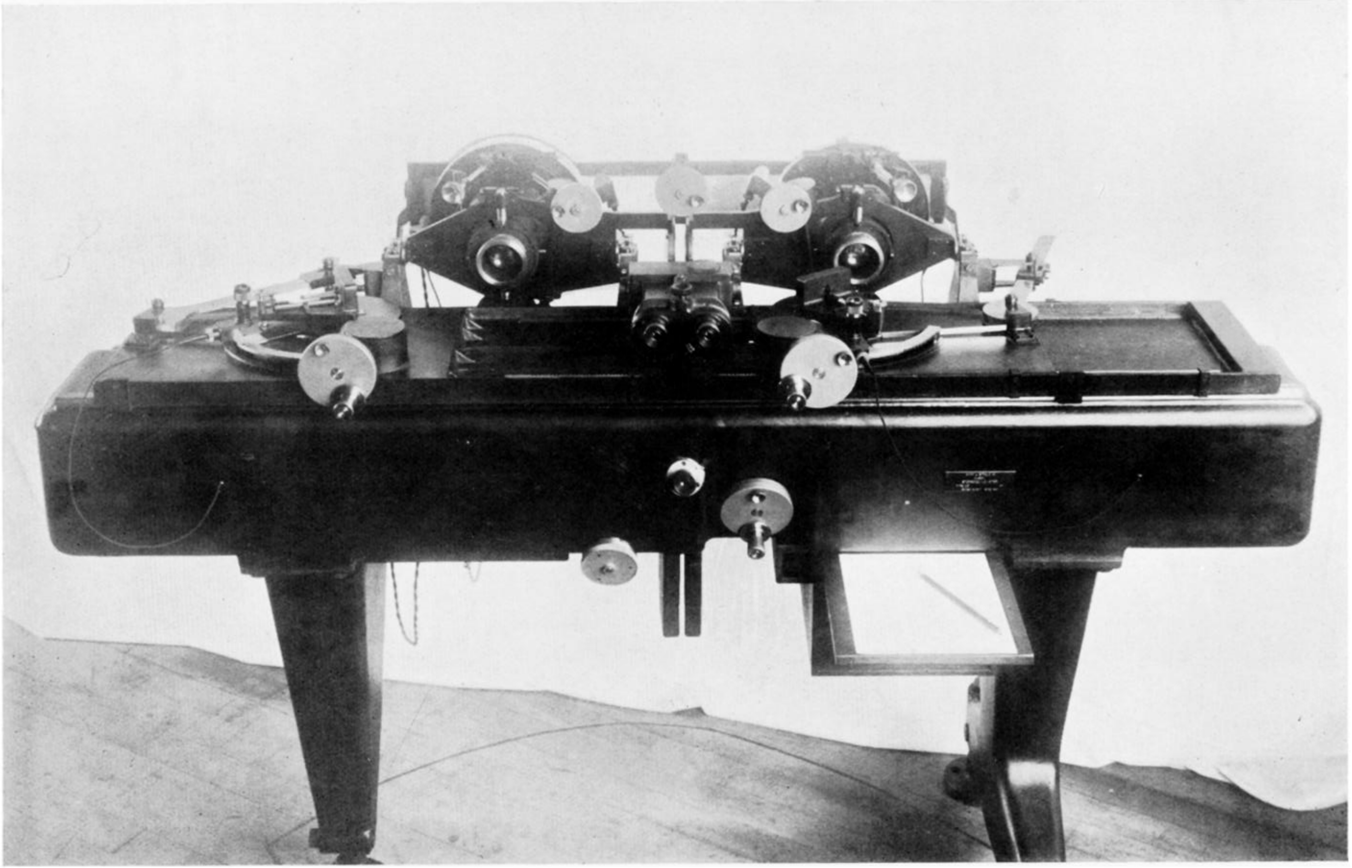
So far, the description of the machine rests on the replacement in the projectors of the original photographic negatives, in which case the landscape is reconstructed true to scale and form, from the point of view of an observer looking at the screen from the position of the projectors. The effect of observation on the other side of the screen is to reverse the apparent relief of the landscape, without modifying the truth of its geometrical reconstruction, and thus to provide the unnaturally flat impression usually associated with pseudoscopic vision. This difficulty is overcome, and the natural appearance of the landscape is also increased, by using glass positives printed from the original negatives. There is no need to introduce any complicated system of optical inversion so dear to the hearts of Continental designers.

### *Setting Movements*

To re-establish the photographs in their correct relative positions, the following movements are provided:

To re-establish the internal perspective of each photograph in relation to the projector lens, the photograph is given two motions of translation in its own plane and one motion at right angles to its own plane. The extent of these motions is determined by calibration of the field camera, and the corresponding adjustments in the machine remain fixed for use with a particular camera.

To obtain the external perspective the photograph may be rotated in its own plane, and the projector as a whole may be tilted about an axis passing through the front nodal point of the projector lens (*22*–*23* in Fig. 6). These two motions enable the marked plumb point of an air photograph to be brought on to the counterpart in the machine of the plumb line in Nature (that is, the perpendicular on the screen from the front nodal point of the projector lens). A further rotation of the whole projector about this plumb line allows for the external orientation of the photographic perspective. In dealing with air photographs, these latter motions of the projectors are worked until correspondence of photographic detail is secured in the vicinity of the plumb points.



4. The Fourcade Stereogoniometer

5. *The Barr and Stroud Photogrammetric Plotter*

In future models it will probably be advisable to replace these movements of each projector by one rotation of the photograph—in its own plane—and one tilt in each of the fixed X and Y directions. This would enable the principle of correspondence setting to be applied almost as well as in the Fourcade machine itself and far more rapidly than is possible with the involved geometry of the Continental machines. The method of setting would be approximate, but would probably attain sufficient accuracy without prolonged successive approximation—especially in the case of vertical air photographs.

One projector may be moved independently of the other in the X direction. The amount of this motion is determined by a final separation of the two projectors equal to the length of the base—to the required scale of plotting—plus the length of the "comparator base."

One projector is given an offset movement in the Z direction equal to the difference in altitude of the two air photographs—also to the required scale of plotting. A similar offset movement in the Y direction is provided for setting an inclined base in the case of ground photographs.

Similar movements, equal to half the corresponding projector movements, are imparted to the auxiliary lens systems.

X, Y and Z scales are provided to enable the relative co-ordinates of any point in observed coincidence with the comparator floating marks to be read off direct.

### *Mechanical Details*

Such details of operation as have not been described above may best be gathered from the photograph of the actual machine reproduced in Pl. 5.

The X, Y and Z control wheels are placed on either side of the observer. Clutches are provided which enable the drawing board to be moved independently of the projectors (to set for the origin of the plot) or coupled to the X and Y (or Z) projector movements. During the plotting of air photographs the main controls are moved until a fresh patch of detail is thrown on the screen. The comparator, to which the drawing pencil is attached through an extension arm, is then moved over the screen image with the floating mark in successive contact with photographic detail which it is desired to plot. An occasional turn of the Z control is required during this process to bring the floating mark to equality in depth with the stereoscopic image, though no great accuracy is required in this respect. To trace contours, the Z control is fixed—at the required height—and the floating mark is moved in apparent stereoscopic coincidence with the ground, either by the X and Y projector controls, or—locally—by moving the comparator.

By means of two suspension wires led over pulleys and attached to the same balance weight, the comparator is prevented from rotating but is otherwise free to move in two dimensions. This motion is so well balanced that no difficulty is experienced in tracing continuous detail in two dimensions, especially as the movement of the comparator is parallel to the shape of the detail. The comparator may be moved by one hand or two, and forearm rests are provided for steadiness.

The drawing pencil can be raised out of contact with the paper, either temporarily or permanently, by means of a lever and catch placed convenient to the observer's left hand.

The screen may be moved bodily up and down by means of the screen control, and at the same time the comparator may be swung round through 180° to observe on the screen in its lower position. This device allows the whole machine to be reduced in size and yet deal with photographs considerably tilted (up to 45°) in the Y direction. Air photographs tilted more than 45° in the Y direction may be dealt with by an interchange of the Y and Z plotting movements as in the case of ground photographs.

The British soldier is in the habit of describing his tools by affectionate, if frivolous, nicknames, and as the name Big Bertha was mentioned in the discussion, it becomes necessary to add a word of explanation as to size. The actual space occupied by the machine may be gauged from Pl. 5, and admittedly exceeds that required for some Continental machines. The first model was designed according to specification for a whole range in permissible size of photographs up to $9\frac{1}{2}$ in. × 7 in., and for a range in focal length up to 12 in. A 20-in. focal length, in use by the French at the time, was given up only after the main structure of the machine had been completed. The machine, moreover, was designed for every conceivable combination of tilts and base lengths, and for a wide range in plotting scales. At the time the machine was designed, no practical experience was available regarding possible limitations in these respects—the design of air cameras was, for instance, fluctuating from month to month—and there was no alternative but to make provision for every probable, or even possible, case. The penalty of increased size had accordingly to be paid, but for an experimental first model this was not considered a serious disadvantage. The conditions are very different now. Air cameras for instrumental surveys are rapidly crystallizing into a standard size of 5 in. × 5 in. × 5 in. (focal length) as a just compromise between aircraft space, weight, angular field, and the interpretable scales of photographs exposed from economic altitudes. The types of air photographs for which it is necessary to legislate could, for all foreseen practical purposes, be restricted now to verticals and pairs of lateral obliques equally tilted to $20° \pm 5°$. The range in plotting scales could also be considerably restricted. In these circumstances, a very much more compact and accurate machine could without the slightest doubt be constructed on this principle. There is no justification for an unfavourable comparison in this respect between other machines and the first Barr and Stroud model, with its wide range of application.

*Characteristics*

The chief advantages which may fairly be claimed for the Barr and Stroud machine are simplicity and ease in plotting.

The greater ease of plotting in the Barr and Stroud machine is at once apparent to any one who has worked with it and with other machines. All the observer has to do is to follow the course of detail as he sees it by a single movement which directly copies the apparent shape of that detail. If the observer sees a square or a circle he traces a square or a circle with the comparator by moving the floating marks along the outlines of the detail which it is required to plot. It is true that a certain amount of theoretical error is introduced in the process, owing to aberrations of the auxiliary lens system, but the extent of this error may be controlled at will by limiting the area traced at one setting of the projectors—thus using a principle with which all practical surveyors are fully acquainted. The projectors can at any time be moved to bring in a new area, and no accurate adjustment is needed of the amount of such motion. Contrast this with the "one-man-band" operation of other machines, in which the observer has to follow the course of detail running in any direction by compounding the independent effects of turning two handwheels, at the same time turning a wheel with his foot. I am well aware that good continuous plotting can be carried out under these latter conditions, but only as the result of prolonged training.

The drawing-board of the Barr and Stroud Plotter is placed close to the observer, who can consequently see exactly what he is doing during the process of plotting.

As regards simplicity, there are no redundant movements involving complicated cam mechanisms, and no reversals or changes in geometrical direction which oblige the observer to imagine himself turned inside out or standing on his head to obtain a clear picture of what he is doing in setting the machine. The principles and operation of the machine can be learnt in a few hours' actual work, the makers' adjustments and calibration are simple and direct, and the user's adjustments are simple and few.

It may be argued that complexity in machine construction is a matter for the designer and is no concern of the user, who does not need to understand its working thoroughly. With that view I most heartily disagree, and I base my opinion on an intensive experience of this type of machinery. Sooner or later the rule of thumb operator makes a mistake and may spend days locating it. If the machine goes out of adjustment or has to be moved, he is helpless and has to call in the maker. From the day of its delivery, the Barr and Stroud machine has been under intermittent test—much of the work being done by a draughtsman—and not once have we been compelled to call in the advice or explanation of the makers. I have yet to learn of a Continental machine being put to work at a considerable distance from the factory and without the assistance of the makers or without personnel specially trained by the makers.

## DISCUSSION

Before the paper the PRESIDENT (Colonel Sir CHARLES CLOSE) said: Captain Hotine has very kindly consented to give us a paper on "The Application of Stereoscopic Photography to Mapping." We are all, in a general way, acquainted with what is going on in the direction of stereoscopic mapping, but it is not everybody who has had actual practice in the matter. All these new methods, which are extraordinarily fascinating in themselves, will ultimately depend upon their value in cheapening surveys. I think, of course, there are some instances in which stereophotogrammetric methods will be used whether they are cheap or not, because they may be the only methods available for that particular problem, but in general we expect that these methods will have to justify themselves financially. I will not say any more about that point now, but ask Captain Hotine to begin his lecture.

*Captain Hotine then delivered the lecture printed above, and a discussion followed.*

The PRESIDENT: Captain Hotine is serving with the Geographical Section of the General Staff under Colonel MacLeod. We shall be glad if Colonel MacLeod will say a few words.

Colonel MACLEOD: Before making any comments on the paper I would like to pay a tribute to the work which Captain Hotine has done on this subject. I think I can claim to be as well qualified to do that as anybody, because now I am the only member of the Air Survey Committee, which deals with this matter, who has served on that Committee since its inception, and I can recall our ideas on this subject when Captain Hotine joined the Committee. We had talked a good deal and we had made a number of suggestions and discussed them, but when it came to actually doing a job of work, we were, as the story goes, all of a-tremble; we did not seem to be able to get on at all. I would not have you think that we achieved nothing: that would be doing us an injustice. After the war we on that Committee not only had to get our theoretical ideas in order but we also had to devise and get constructed apparatus with which to carry them out. That naturally took time and cost a good deal of money, but for the most part it did eventually materialize.

The first thing we wanted in order to progress with this subject was a properly calibrated camera. That we had not got, to start with, but ultimately we did get it, thanks largely to Wing-Commander Laws, who is with us this evening. After that we had to get plotting machines of various kinds, and the production of these instruments was the first task the Committee had to tackle. Though we got these things made, I think we must now admit that we really did not do very much more than "clear the ground"; indeed, the uncharitable might say that we left a good deal of junk lying about on it. However, I think much of it was useful junk, and when Captain Hotine came along he was able to pick out the useful bits, cement them together with ideas of his own, and produce the working system which he has described to us and the products of which are on the screens in this room. It is a working system which has, on the occasions we have tried it, given surprisingly good results.

Looking back, I cannot help thinking that one of the reasons why we made such poor progress was that our experience in France actually misled us. As you know, in France we were engaged in producing maps from air photographs, but we hardly realized that we were dealing with a special case. We dealt there with the individual photograph, and after the war when we had to solve a more generalized problem we tried to do so by methods which had served us in France: in other words, by working on the individual photograph. It was Captain Hotine who brought home to us that the " unit " as regards air photographic mapping is the overlap—the stereoscopic pair—not the single photo.

I have to plead guilty to having, at a meeting of this Society, belittled the stereoscopic principle on the ground of the restriction thereby imposed on the length of the base; I thought that it was not taking the fullest advantage of the mobility of the aeroplane. Mr. Fourcade and Captain Hotine have shown us how to get over that difficulty, and though after my former failure it may be a little rash for me to venture another prophecy, I am now satisfied that it is on the stereoscopic principle that the future of air surveys will rest.

A word about the stereoscope. I do not expect many of you have used it. Some people are, I think, at first inclined to distrust the stereoscope as an instrument of precise measurement. There seems to be altogether too much scope for judgment in using it; in fact, one is apt to think that with an instrument of that sort in the hands of a man who is not thoroughly trustworthy, judgment may very easily degenerate into "fudgment," and that, as you know, is the surveyor's most heinous crime. Actually I think that is not so. Captain Hotine will bear me out when I say that with practice soon comes a confidence in the stereoscope which is amply justified by results.

Before sitting down I would like to add, with reference to the President's remarks on the economic aspect of this matter, that of course there is another aspect which I in my official capacity am concerned with, namely, the military aspect. I personally regard the perfection of air photographic survey methods as a scientific development whose military importance can hardly be exaggerated. I think that when it is well understood and properly exploited it will put into the hands of the civilized and educated man a weapon—or rather, a method of fighting—which will prove perhaps more effective even than the armoured vehicles that now loom so large in the public eye. It would require a good deal of explanation to say why that is so, and there is no opportunity for me to go into that here, but I believe that statement will prove correct, and, what is more, I believe that this method of fighting will be particularly valuable because it is one which the illiterate and the savage cannot use.

Brigadier E. M. JACK: I would like to ask one question. How long did the setting of the photographs recorded take?

Captain HOTINE: The first pair took a whole day; the second pair three-quarters of an hour. We have not tried the third pair yet, but I think we shall be able to cut down.

Brigadier JACK: The only other thing I would like to do is to express the very great interest with which I have heard Captain Hotine's paper and to congratulate him on the lucidity and clearness with which he delivered it. It really was delightful.

The PRESIDENT: I will ask Mr. Hinks if he will kindly say a few words on the subject, which he has studied a good deal.

Mr. HINKS: I should like to express my great pleasure at having heard this paper, and equally my great gratification that we shall be able to publish in the *Geographical Journal*, in the course of two or three months, some description of methods that many of us have wanted to know about for a long time and now, for the first time, have the opportunity of judging. There has been, we have heard, a mysterious creature which has been kept somewhere in the War Office, which is known, I believe, by the name of "Big Bertha," and I am interested, first, to note that Captain Hotine speaks of her—the Barr & Stroud machine—as "superior in conception and vastly simpler than any Continental model." That, of course, is a very strong compliment to Big Bertha, but it clearly necessitates that we should be able to have her portrait and, I hope, a description of her constitution published in order to judge of the merits of the statement. I think I am right in saying that at present nobody, except one or two in the War Office, knows anything about the optical design of Big Bertha or the geometry of the method. I feel that now we have been told it is "superior in conception and vastly simpler than any Continental model" we are justified in expecting this secret to be at any rate partially revealed. We have heard first in this Society of the Stereoautograph and the Hugershoff machine, and more recently, after Major Kenneth Mason had made that very successful photographic survey in the Shaksgam, we had some account of the Wild machine. While Major Mason was actually measuring the plates I was trying to write out the geometry of the thing, and we had a joint paper on the subject. Captain Hotine spoke rather scornfully of the modification by which Wild has made a patchwork of a machine originally designed to work upon the ground. I venture, with all deference to Captain Hotine, to maintain that that is not quite fair. The machine of Wild was originally designed to work either upon the ground or from air photographs. It is perfectly true that Wild found that as soon as he had given an additional motion to the machine he could make it easier to work on air photographs, but I do not think it is just to him to call it a " patchwork system in a machine originally designed to work upon the ground." I am interested to know that Captain Hotine considers, even when that system has been patched up, its geometry is not as successful as that of the Fourcade machine. I asked Captain Hotine—I hope he will accede to my request—to write a page or so in the *Journal* explaining exactly what the geometry of Wild's modification is and how it is that it breaks down. My own account of the machine was written before the latest modification, and although I saw the machine in July at the Aircraft Exhibition at Olympia I am bound to say I did not in the least understand the modification.

The second point that I should like to emphasize is that, if I understood correctly—and I shall be glad to be assured on this point—the Fourcade machine, which was also built by Barr & Stroud, is a very fine solution of the problem of the duplex tilt-finder, and its duplicity—in the good sense—enables one to put together pairs alternately and so step along a long traverse. Colonel MacLeod developed several forms of tilt-finder in the early days of the Air Survey Committee. It is, of course, as Captain Hotine says, possible to add a plotter—that is possible with any machine, though rather a heavy job sometimes—and it will be interesting when he has been able to realize it.

There are many things one might say in discussing this fascinating subject, but I will say only one more. Captain Hotine warned us—I do not know whether he was referring to me in particular—off academic optical objections to his theory. In spite of that warning I would like to remark that at present all the diagrams I have ever seen explaining the optics of this machine show optical rays converging from a pair of eyes towards a plate. I do not say that that way of drawing the thing is necessary to the explanation, but it certainly seems to be involved in the explanation, and it also seems to me to be plainly false, because there is no question whatever that in any of these stereoplotting machines the axes of the eyes are governed by lines between the optical centres of the eyepieces and the floating marks, and in order to keep those floating marks fused the eyes must remain parallel. There is no doubt about it that the idea that the eyes converge to get these optical effects is totally wrong. I do not say that is the explanation always given, but it is too often given. There is something very much more occult and mysterious about it than mere convergence of the eye. I think Captain Hotine will agree.

Captain HOTINE: I will answer the question, but I do not promise to agree.

Wing-Commander LAWS: I am not sure that I can contribute anything useful to the discussion. I have only dealt with the air side of the problem. It might be of interest, however, for me to say that any air work called for in connection with the making of these various maps has not presented any problem which could not be overcome by any reasonably well-trained pilot. That seems to me to be important from both the Service and commercial points of view. I would say that any scheme produced which necessitated the employment of a pilot highly skilled in surveying would be a failure from a Service point of view. I can assure you that the method described by Captain Hotine does not require any special knowledge. We are satisfied that under normal conditions we can meet the requirements.

Captain KEMP: I am afraid I have nothing very useful to add, but I would like to congratulate Captain Hotine on his very clear and interesting paper, and to say that I hope Colonel MacLeod's views can be forced upon the authorities so that the Committee may have better funds in future.

Major COCHRAN-PATRICK: The President has stressed the point of economy in air surveys and Colonel MacLeod has shown the importance of the military side, but there is one aspect which is really even more important and which has not been touched upon, and that is the question of speed. By using air surveys we have enormously hastened the whole operation of mapping. To digress for a second from the topographical scales mentioned in the paper, I might cite a point that has come up in a recent survey of Rio. We have only one equivalent survey with which we can compare it, and that is the survey of Berlin. We have heard from our manager in Rio that he has completed in one and a half years a job equivalent to one which took twenty-two years in Berlin. That is on the scale of 1/1000. We were definitely using ground methods supplemented by air photography; there was no question of stereoplotting instruments. Where we gained, of course, was on account of the fact that we did not have to force our way into backyards and get access to private property. We find that actually the amount of checking on the ground which has to be done in the detail work is surprisingly small.

Captain Hotine has said a great deal about the various instruments which were produced in the early stages, but he has really said very little of the instruments which he has been mainly responsible for producing and which, of course, are applicable to the smaller topographical scales. I should like to pay a tribute to his ingenuity in originating the idea of the parallactic grid and in producing in this practical manner a two-dimensional instrument instead of the three-dimensional machines with which we had been trying to compete. We in our company have used those topographical stereoscopes of his a great deal and have had much practice with them; we find everything he claims works out absolutely exactly. In fact, the only alterations which we have had to make are in detail operations. For instance, in the drawing on of contours we find that the average draughtsman is not particularly good at lifting a grid and drawing a contour on the photograph underneath, so that it is simpler, in spite of the extra expense, for us to make glass positives, put the grids under them and draw the contours directly on to the positive without interfering with the grid at all and, in fact, while looking at the grid. I should like to thank Captain Hotine very much for his paper.

Mr. G. T. McCaw: I should like to follow up the preliminary remarks with which you, sir, opened the meeting. Omitting military and some special requirements, I would refer to-night to the economic adaptation of air photography to civil ends. Of the numerous inquiries which have come before the Air Survey Committee, none has been more insistent in peace than the question of cost. In this matter there has been a gradual evolution of thought and method—as indeed Colonel MacLeod has already hinted. Starting with the individual photograph, we began by thinking of the means of bringing it into terms of ground controls. The process was not simple. Faced with this difficulty, we were forced to the conclusion that the application of such methods would damn for ever the employment of air photography in an economic sphere.

There was in existence, however, though in rather crude form, the graphical method of radial-line plotting. In the hands of Captain Hotine the method was developed, chiefly by the adaptation of a simple stereoscope to the improvement of the orientation and spacing of photographs taken throughout a strip flight, and by the invention of a transparent grid to gain sufficient knowledge of relative heights. This "Arundel" method in skilled hands proved rapid and inexpensive, while giving the accuracy required for topographical maps on common scales. For more accurate work on large scales and for mechanical plotting, the difficulty remained practically unsolved until Mr. H. G. Fourcade—one of the earliest workers in photogrammetry—came forward with the Correspondence Machine which we have named the Stereogoniometer.

In both the graphical and mechanical methods mentioned there is a common fundamental principle—that of utilizing the correspondence between overlapping photographs of a strip to set up their own control. This process is, of course, not continued indefinitely, but it is continued far enough to remove air survey from the academic to the economic sphere. Mapping from aloft would never have made headway had the fundamental principle not been accepted that, since it is economically impossible to fix ground controls for every photograph, air survey, to be economical, must be to a certain extent, as it were, self-supporting. That it can be so has been the text of the lecture to-night.

Mr. M. A. SPENDER: I wonder whether there would be any chance of bringing this method down to earth again. It has always struck me that the trouble with the Wild instrument is that you have to know far too much. You have to know enough about the base conditions to tell you everything, and then you have to have the three controls to set the instrument. Is it possible to have a method of control whereby the photographs are their own control—to simplify the whole thing and bring the ground pairs together mechanically into line with the air pairs?

Captain HOTINE: As regards bringing the whole system down to earth again, that is, I assume, the question of making photographs produce their own control, that is what we are hoping to do with the new Fourcade machine. Major Cochran-Patrick has remarked that a glass positive might be used in the Topographical Stereoscope so as to avoid having to lift up the grid plates to draw contours. That instrument was designed primarily for military purposes, and whereas we can always get hold of a paper print and be relied upon not to break it, the same does not apply to a glass positive. I think he may be right in adapting the instrument to the use of glass positives for his own purposes. I do not think we ourselves would be justified in doing so. The draughtsmen in the Geographical Section of the War Office have little or no difficulty in this respect. They get quite used to lifting the grid with one hand and working with the pencil in the other. There is no reason why a draughtsman should not occasionally remember that he has two hands and that both are available.

Major Cochran-Patrick also spoke of speed. On that question I agree with him as regards the speed of plotting on larger scales, but I disagree when it is a question of small scales and open country. If you are out, for instance, to produce a $\frac{1}{4}$-inch map of open country, and assuming you are able to spend the large amount of money required for air photography in hiring a correspondingly large number of plane-tablers, then I have not the least doubt that this army of plane-tablers would beat the aeroplane every time. But, of course, the crucial point is that there is no army of plane-tablers available, not even a British army.

As to Mr. Hinks' objection to my criticism of the modification of the Wild instrument, Wild had originally arranged that photographs exposed in any way, even horizontally or vertically, *could* be set in the instrument, but he had omitted to consider *how* he was going to set them. It was the setting of the instrument which necessitated the patchwork arrangement—an expression to which I still adhere. In fact, if Mr. Hinks will agree that it is necessary to set photographs before one can plot them, I think he will agree that the original criticism holds.

Mr. HINKS: Of course Wild originally intended to make a separate tilt-finder.

Captain HOTINE: Yes, but he did not do so.

Mr. HINKS: No, but he did the other thing instead.

Captain HOTINE: Yes, by patchwork—an afterthought. I think I can promise a description of that elusive lady, "Big Bertha." When I say that the instrument is superior in general conception I really mean it. It is the only instrument of its kind in which you can see clearly what you are doing in setting and what you are plotting. I think those are two very considerable advantages which justify its superiority in conception. That other merit of simplicity can only be justified by a full description of the machine.

I think the only other point I have to answer is Mr. Hinks' question as to a large convergence of the eyes. I should like, first, to say that it is quite true that when you are examining any objects stereoscopically you do not wilfully converge the eyes to the extent shown in the diagram. It would be uncomfortable to do so. But we have to keep such diagrams within the compass of a lantern slide or a piece of paper, and consequently we cannot make the diagram disproportionately large in order to make it look more natural. That, I feel, is not exactly Mr. Hinks' objection; he rather claims that in most stereoscopic machines the actual condition is that the axes of the eyes are not converged at all but are parallel. That, I think, is wrong; certainly in every stereoscopic machine I have examined. The two floating marks are usually fixed in most stereoscopic machines, and they are designed for a certain convergence of the eyes, either by decentring the floating marks or by increasing the interocular distance setting. Otherwise, in cases where two corresponding points of photographic detail are at a greater separation than the floating marks and tend to form an image at a farther distance, the eyes would necessarily have to diverge in order to fuse them.

Mr. HINKS: If you had the eyes directed on those objects. I think you keep the axes of the eyes upon the marks and, by some peculiar process you do not understand, do the fusing; you get the impression of the stereoscopic views round about the floating marks, keeping the axes of the eyes fixed on the marks.

Captain HOTINE: I think you first of all fix the marks and then fix the ground in rapid succession.

Mr. HINKS: I do not think so.

Captain HOTINE: It is perhaps a matter of opinion. The movement is too rapid for one to be conscious of, but I imagine I have given the explanation. In any case it is usual in stereoscopic machines to allow a certain convergence on the floating marks so as not to have any uncomfortable feeling of divergence.

Mr. HINKS: Perhaps I should have said the axes of the eyes remain fixed rather than parallel. The floating marks are fixed and you keep the axes of the eyes fixed—not perhaps strictly parallel, but fixed. It is not a question of altering the convergence of the eyes to get the stereoscopic effect.

Captain HOTINE: I agree that it is *possible* to compare the stereoscopic depths of objects lying within the field of distinct vision without altering the convergence of the axes of the eyes. Experiments made under the instantaneous illumination of an electric spark, when the eyes have no time to alter their state of convergence, have proved this. I do not, however, believe that a sufficiently acute observation can be made under such conditions. In comparing two objects, is it not reasonable actually to look at each in turn? If the two objects are at different depths, looking at them entails an alteration in convergence. In training stereoscopic observers, we find that a common fault is to concentrate too much on the marks, as you are suggesting, and too little on the ground. We get them out of that habit as soon as possible by telling them to concentrate on the ground and ignore the marks. The latter have a strong enough stereoscopic character to force attention, and in the result the observer arrives at the correct state of balance between the two. To concentrate on the marks and ignore the ground, thereby retaining a fixed state of convergence, is roughly equivalent, to use a monocular parallel, to concentrating on the foresight and neglecting the target.

Mr. HINKS: The explanation, I think, lies far deeper than one can go with geometrical optics. We cannot explain by what process in the brain the separate and slightly different images formed by the two eyes in ordinary use are fused into one picture with the sense of solidity; but there is much more in it than any simple question of variable convergence, and I would maintain that we should accept it as a mysterious physiological fact and not attempt to explain it by geometry.

The PRESIDENT: Captain Hotine at the commencement of his admirable paper described how in the early days one was apt to mistake a hill on two photographs. I am afraid that even the plane-tabler does that sometimes. I remember in 1890 in Burma I was given a reconnaissance map made by a staff officer in which appeared a magnificent 5000-feet hill. When I came near the ground I found the hill non-existent; he had his two rays and had identified them wrongly. That might happen to anybody, even to a photographer. I was struck by the progress that has been made in the stereoscopic method. I remember when Mr. McCaw was in Fiji he took some stereoscopic photographs and sent them to Southampton, and we had the pleasure of trying to make a map from them. It was excessively difficult. In those days we used Major F. V. Thompson's machine, and it was difficult to get any sort of coincidence.

Mr. McCAW: Of course there were special difficulties in Fiji.

The PRESIDENT: But the progress has been very great. In reading up this subject I am struck with the difficulty of remembering the names given to these various machines. We have stereocartograph, autocartograph, photocartograph, and stereoplanigraph. It is hard to remember which machine you are dealing with. I wish some simpler form of nomenclature could be devised.

We are glad to hear from Captain Hotine that the British machine has the merit of simplicity. The general outcome of this sort of work is that we shall tend to employ, in future, a few skilled men as opposed to a large number of relatively unskilled men. We congratulate Captain Hotine on the development of the parallactic grid, and are very grateful to him for the paper he has given us. I know you will show your appreciation in the usual way.

# HIMALAYAN NOTES

## I. *Identification of Karakoram peaks by the stereoscope*

MAJOR Kenneth Mason sends us tracings of two panoramas, F and I in Dr. De Filippi's 'Karakoram and Western Himalaya,' taken respectively from the ridge east of the Sella Pass, and from the southern ridge of Staircase Peak, and looking eastward over the Shaksgam valley to the country which he surveyed with the photo-theodolite in 1926. By a study of his pairs of photographs in the stereoscope he has been able to identify with certainty a large number of features in the panoramas taken on the Abruzzi expedition, and he remarks that without the stereoscope these identifications were not possible, while with it they were fairly obvious.

## II. *An unpublished report on Hunza glaciers*

We are indebted also to Major Mason for a copy of a report on Hunza glaciers, made by Captain F. H. Bridges in 1908, which has remained unregarded in the records of the Political Officer at Gilgit for some twenty years. It