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horizontal collimation. The objective is carried on a rising front with stops working in a series of holes, and the front carries two arms extending backwards to the plane of the plate to mark the position of the horizontal through the optical centre.

A theodolite is mounted on top of the camera, with horizontal circle reading to 50 centesimal seconds, or $16''$, by verniers. It can be set by stops to read 0° , 100° , or $100 \pm 35^\circ$, or can be set to any other angle by the horizontal circle. Vertical angles are read to the same degree of accuracy. The telescope of the theodolite has internal focussing by a third lens, and the horizontal collimation is adjusted by the same device of an excentric lens. There is no adjustment to the horizontal axis for level.

For measuring the length of the base the theodolite can be rotated by a micrometer screw with hemispherical point acting on the hardened flat face of an arm which is fixed to the theodolite. The head of the screw therefore reads tangents of the angle of rotation, and allows direct readings on a stadia rod mounted at the other extremity of the base perpendicular to its length. This is elegant, but since the point of the screw works up and down the surface, it seems to be likely to wear a groove, and I understand that the French do not consider it sound.

There is a figure of the theodolite and camera, with further details, in the description by M. Paul Corbin published in the *Revue des Sciences pures et appliquées*, 30 March 1914.

The plates used are 18 cm. $\times$ 13 cm. They are very fine-grained slow plates, orthochromatic on patent plate glass.

STEREOGRAPHIC SURVEY: THE AUTOCARTOGRAPH

Lieut.-Col. M. N. MacLeod, D.S.O., R.E.

*Read with the preceding paper at the Afternoon Meeting of the Society,
13 February 1922.*

THE autocartograph is an apparatus designed by Professor R. Hugershoff, Professor of Geodesy at Dresden University, for applying the principles of stereogrammetry to aerial photographs. Until lately this principle has only been used with photographs which are taken exactly parallel and horizontal. Orel's stereoautograph applied it to photographs which are not exactly parallel, but which must be horizontal. Hugershoff claims to advance a step further and apply it to any two photographs which are sufficiently parallel to give the stereoscopic effect of relief. The autocartograph is designed to correct automatically both for non-parallelism and for tilt.

This is effected by the employment of an instrument called by the Germans a "Bildmesstheodolit." It will be advisable therefore to give a brief description of this instrument as a preliminary to that of the autocartograph itself. The Bildmesstheodolit, in its original form, consists of a telescope of low power mounted so as to rotate about two axes, one

THE AUTOCARTOGRAPH OF HUGERSHOFF

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horizontal, the other vertical, whose intersection is in front of the object glass and coincides with the centre of rotation of a holder for the photograph.

This holder consists of a metal casting, with balance weights, and may be regarded as the aerial camera placed in front of the telescope so that the latter can look into it backwards through the lens. The holder rotates about the same horizontal axis as the telescope and carries a lens, identical with that used in the aerial camera, fixed so that its principal points coincide with the intersection of the telescope axes. It is provided with a special plate carrier which enables the plate to be rotated in its own plane about its centre or any other adjacent point.

An oblique aerial photograph can be placed in such an instrument, and can be looked at, through the telescope, so as to give a view virtually the same as that which would be obtained through a theodolite set up and levelled at the point from which the photograph was taken. It is only necessary to rotate the photograph in its carrier until the axis of tilt is horizontal and to tilt the holder to the same extent as the aerial camera. Vertical and horizontal angles to any point visible on the photograph can then be read off directly on arcs provided for the purpose.

This principle is used in the autocartograph to correct for non-parallelism and tilt of the photographs used. Each photograph is viewed through a Bildmesstheodolit of special design, of which the plates and plate-holders must be set in positions determined by a preliminary calculation.

This preliminary calculation involves the determination of :

- (i.) The spatial coordinates of the two view-points.
- (ii.) The direction of the optical axis of each photograph in a vertical plane.
- (iii.) The direction of the optical axis of each photograph in a horizontal plane.
- (iv.) The direction on each photograph of the axis of tilt.
- (v.) The basal angles of the triangle formed by the two view-points and one previously fixed point in the landscape.
- (vi.) The distance apart of the two view-points.

Determination of these elements is effected by a "resection" in space from three or more points, which have been previously fixed by independent methods, and which appear on the photographs. The photographs must be taken so that a certain area of previously surveyed ground appears on them, preferably in the foreground.

The camera used for taking the photographs is a hand-held camera of special construction, noteworthy, however, only in respect to the arrangements provided for ensuring that the plate is accurately in the focal plane when exposed, for the refinement in the collimating marks defining the optical axis, and for the type of shutter, which is a "between lens" shutter giving an exposure of about $1/200$ sec. The focal distance is accurately

determined after the lens has been fixed in position by comparison with theodolite observations.

The photographs are taken over the side of the aeroplane in a direction roughly at right angles to the line of flight: the height depending on the scale of the map. For a scale of $1/10,000$ Hugershoff gives 1600 metres as a suitable height, 3000 m. for a scale of $1/25,000$. The camera is held, by means of a small bubble clinometer, at an angle of approximately 30° to the *horizontal*. The interval between photographs is given as about 1 kilometre.

Photographs taken thus are expected to include in the foreground at least three points whose heights and positions are known. From these the position of the aeroplane at each exposure is deduced.

The computation of this resection in space is a considerable matter. Hugershoff adopts a "trial point" method which he has described in his book, and which, he claims, is the simplest available, and gives an accuracy of ± 1 metre in the resulting position assigned to the viewpoint, of about $\pm 30''$ in the angle of tilt, and $\frac{1}{2}^\circ$ the direction of the axis of tilt. He uses the Bildmesstheodolit for determination of the trial point and for shortening the computation in various ways. For example, when the "trial point" has been found the axis of tilt can be found in a few minutes by trial and error with the Bildmesstheodolit.

Having completed these preliminary calculations, operations are transferred to the autocartograph, which is shown diagrammatically in Figs. 1 and 2. It consists of a binocular stereoscopic telescope with a Bildmesstheodolit placed in front of each object glass.

Owing to obvious mechanical difficulties the telescope cannot be mounted on two axes as in the ordinary Bildmesstheodolit. Instead, the object glass of each telescope is made to rotate in a vertical plane, and the azimuthal movement is given by rotating the photograph holders in a horizontal plane. The axes of rotation intersect in the centre of the lens of the Bildmesstheodolit. The azimuthal movements are transferred mechanically to two arms or levers travelling over a plotting board in front of the operator, and the vertical movements transferred similarly to two height arms or levers, one at each side of the apparatus.

Scales or arcs are provided to indicate the extent of such movements. The horizontal arcs are read by means of a microscope placed below the binocular.

The azimuthal levers are pivoted at the operator's end at an arbitrary distance apart, and are connected to the Bildmesstheodolits by clamps. At their opposite ends they are connected by a distance piece carrying a scale. This distance piece can slide up and down the arms, remaining however in all positions parallel to the line joining the pivots.

The height levers are also pivoted at the operator's end, and pass at their opposite ends through a slide moving along a graduated bridge connected to the distance piece already referred to; by suitably setting

the zero of the scale on the bridge, a pointer on the slide will indicate the height of any object plotted on the plotting board.

Plotting is effected by means of a pencil attached to the distance piece, and raised or lowered by an electrical control from the operator's seat.

This pencil follows the apparent movements of a mark or pointer in the field of view of the binocular. Any feature such as a road or railway visible on the photographs can be drawn in quite automatically, while the height of any point can be read off on the scales over which the height levers travel.

If it is desired to draw in a contour the height levers are clamped to the scales at the particular height required. The operator then moves the pointer in the field of view so as to keep it in apparent coincidence with the surface of the ground. The pencil will then trace out a contour line of the required height.

Other attachments to the apparatus, which I need not describe, are provided for drawing profiles or sections of the ground along any particular line—say a road or railway—and also for redrawing an ordinary map in two ways so that when the drawings so obtained are viewed in a stereoscope the contour-lines appear in stereoscopic relief like a cardboard relief map.

The following is the method of setting or adjusting the instrument after the preliminary calculations are complete:—

(i.) The photographs (glass positives) are placed in the holders with their axes of tilt horizontal.

(ii.) The holders are inclined and clamped at the calculated angles of tilt.

(iii.) The azimuthal levers are set at angles with the line joining their pivots corresponding to the basal angles of the triangles formed by one fixed and the two view points.

(iv.) Keeping the arms at this angle, the distance piece is moved until a pointer on the right-hand slide reads on the scale a distance equal to the stereoscopic base (*i.e.* between the two view-points at the required scale). The slides and distance piece are then clamped together.

(v.) The Bildmesstheodolits, not yet attached to the horizontal or vertical arms, are rotated until the stereoscopic view is obtained, and the pointer appearing in the field of view is "laid" on the fixed point both as regards direction and depth. In this position they are clamped to the horizontal arms.

(vi.) The vertical arms and the zero of the height scales are adjusted so that the height reading of the point is correct, and the height lever pivots are then clamped.

(vii.) The pencil can now be lowered and follows the apparent movements of the pointer in the field of view.

This pointer is really a mark in the centre of the focal plane of each

eyepiece. The eyes combine these two marks to form a single image, which is at infinity when the optical axes, or central lines of sight, of each photograph are parallel.

Revolving one photograph relatively to the other causes this image to appear to advance. This movement is given by a wheel worked by the operator's right hand. This screws the distance piece in or out, thus altering the relative orientation of the two photograph holders. Apparent lateral movement of the pointer is given by a wheel worked by the operator's left hand. This moves the distance piece from side to side, and with it both plate holders. There remains finally the vertical movement, which is given by a plate suspended below the apparatus and revolved by the feet. These movements proceed with reasonable, if not with remarkable, smoothness.

The time-table of work given by Professor Hugershoff for a pair of photographs is: one day for photography, two days for the preliminary computations, and one day for plotting.

The area covered by a pair of photographs is said to be about 30 square kilometres.

Having no experience of the practical working of the instrument, I will not venture to criticize these figures beyond giving my impression that the use of a 13×18 cm. plate in conjunction with a lens of only 16.5 cm. focal length seems to be expecting rather too much in the way of definition from the lens.

As regards the theory I would make the following comments :

(1) The method of resecting in space by means of a "pyramid" of comparatively small apex angle appears to be rather weak.

This, coupled with the fact that the photograph viewed through the Bildmesstheodolit looks distinctly "woolly," makes me think that the "probable error" claimed for such resections does not err on the side of caution.

(2) The stereoscopic method requires exceptionally good definition in the photographs. The area to be mapped lies in the background of the photograph, and it is doubtful if the definition and contrast of a distance landscape will be really satisfactory unless the features are very prominent. I personally found it most difficult to judge the apparent coincidence of the pointer with any but the most prominent landmarks on the photographs exhibited. Admittedly I was a novice. No doubt also I lacked in some degree the gift of seeing relief in a stereoscope.

(3) The most serious objection, however, seems to me to lie in the use of the stereoscopic principle at all for *accurate* aerial work. The *ground* surveyor only uses this principle when circumstances compel him to use a short *base* for fixing distant points. He uses it only when his stations of observation lie on mountain-tops which are difficult to climb. He cannot climb more than a few without unduly prolonging the time and labour required for his work, and having got to the top of each he wishes to

Simplified Diagram of the AUTOCARTOGRAPH.

FIG. 1. Plan.

FIG. 2. Elevation.

Wheel acting on distance piece affecting the convergence of the levers

Wheel actuating left hand
and therefore both levers.

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Wheel acting on distance
piece affecting the convergence
of the levers

↓ Plate actuating the vertical movement.

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STEREOGRAPHIC SURVEY.
MacLeod & Hinks.

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survey as much as he can from there. The stereoscopic principle is only used because it is believed to give more accurate results from a short base than "independent" observations from the two ends of it.

The "mobility" of the aeroplane is, however, not restricted by the configuration of the ground. Its most important and characteristic attribute is in fact its independence of terrestrial obstacles. It seems to me to be a fundamental mistake to adopt a method which makes no use of this unique power until it is found that no other is practicable.

No doubt in certain types of country, such as parts of Palestine where the ground is much "accidenté" and at the same time devoid of conspicuous features and landmarks, the stereoscopic method would be extremely useful, but I would prefer to regard it as a preliminary to other and more accurate processes. I doubt, in fact, if the autocartograph can really yet be called a survey instrument of precision. In any case I feel fairly confident in saying that it has not yet undergone really searching tests.

I have received recently from the makers a report prepared by Herr Treitschke, head of the Saxon Topographical Survey, on a comparison of a plan prepared with the aid of the autocartograph against the ordinary 1/10,000 topographical map.

This plan was prepared from a single pair of photos, and no details are given of the data on which it is based. The comparison was made by measuring the 137 distances between 55 points on plan and map. The distances varied between 150 and 700 metres. The mean discrepancy is given as 0.63 per cent., individual errors varying from -9 to +8 metres—distances which, it will be noted, are only just plottable on this scale. The comparison of heights of the same 55 points, ranging over a vertical interval of some 120 metres, showed a mean divergence of ± 1.22 metres, individual errors varying between -2.7 and +2.7 metres.

These figures are remarkably good, but in the absence of precise information as to the data, etc., from which they were obtained, it would, I think, be premature to draw final conclusions from them as to the ultimate value of the autocartograph. It would appear however that the instrument has considerable possibilities for carrying out *detail* survey, though it seems unlikely, owing to its great cost, that much use will be made of it until further tests have been made and more information is available as to the comparative cost of maps made with it as against present or alternative methods.

Discussion following the two papers by Mr. Hinks and Colonel MacLeod.

Colonel E. M. JACK: I agree with Colonel MacLeod that, on general principles, it is to some extent wrong to use the stereographic principle for aerial work, because, as he said, by so doing you forego the advantages given by the mobility of the aeroplane. On the other hand, if you make no use of the stereographic principle you abandon the advantage of being able to do auto-