USE OF AIRCRAFT FOR SURVEYING

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The **U. S. Coast and Geodetic Survey** from whom the International Hydrographic Bureau had requested particulars of its method of employing aerial photographs for hydrographic surveying, has replied that it has only infrequent occasion to utilize aircraft in surveying operations, but it addressed the following documents concerning the subject to the Bureau :—

(*a*) Aerial Survey of the Mississipi River Delta, by Lieutenant G. S. MATTISON, U. S. C. and G. SURVEY — Special Publication N° 105. Washington, 1924.

(*b*) A report of the Committee on Photographic Surveying of the federal board of Survey and Maps, May 24, 1926.

(*c*) A Lecture prepared in the U. S. Geological Survey on *"The Compilation of Maps from aerial photographs."*

(*d*) Topography and Surveying — Aerial photographic mapping — War Department, Washington, January 23, 1925.

From these very interesting documents, which demonstrate that the use of aerial photographs for surveying has now entered on a truly practical period — and particularly from the last — we have extracted some details which appear to us to be particularly applicable to coastal surveys for charts, and which have not yet been published in the Review. But operators will derive great benefit from the study of the documents themselves, which contain much other useful information. They will observe that the photographic method has been found especially advantageous in charting coast lines, and stretches of coastal country, which are difficult and tedious to survey by ground methods.

INSTRUMENTS.

Various types of cameras have been used :—

(*a*) *K*3 and *K*8 film type cameras are entirely automatic, and their rolls permit 100 negatives to be taken. They are equipped with between-lens shutters, as is the case in the following apparatus also .

(*b*) The Brock plate camera, which takes 50 plates — and can be rapidly recharged during flight ; the focal length is 8 ½ inches (216 m/m), the dimensions of the plates being 6 ½ by 8 ½ ins (165 m/m by 216 m/m).

(*c*) *T* type — tri-lens film camera, of which the central lens (focal length 6 ½ ins — 165 m/m) has its optical axis as near as possible to the vertical — and of which the two others (focal length 7 ½ ins. — 190 m/m 5) have their axes inclined at angles of 35° to the optical axis of the centre lens. The total field is 120° across the direction of flight (*see* figures 1 and 2).

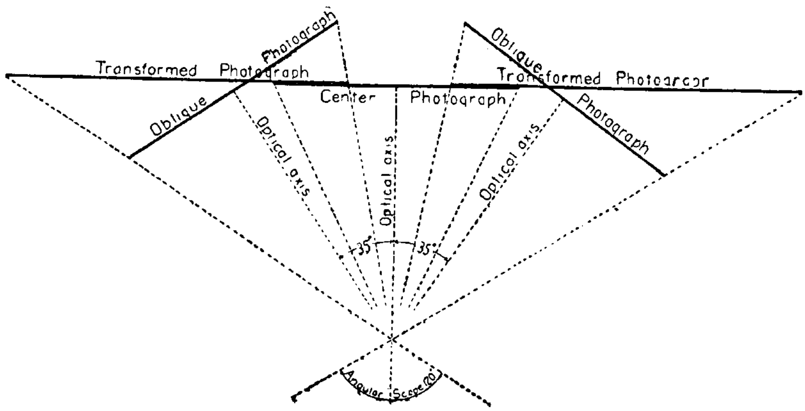

FIG. 1. — *Diagram of Tri-lens camera.*

Angular Scope 120°. ....Champ angulaire 120°.
Optical axis. ....Axe optique.
Center photograph.............................Photographie centrale (verticale).
Oblique photograph. ....Photographie oblique.
Transformed photograph. ....Photographie redressée.

This apparatus has been much in use in latter years, but is now commencing to be replaced by cameras of 4 and even 5 lenses. The appliances with very large field do not necessitate the determination of such a great number of points on the ground, and are of advantage in calculating altitudes. Those which have 4 or 5 lenses, moreover, assure better orientation of the photographs when they are restituted (*see* fig. 3).

Oblique photographs which have been taken with these appliances are projected into the plane of the vertical photograph taken with the first lens (composite vertical photographs) by means of the MOFFIT photographic transformer or by the Transforming printer. (this is capable of transforming at angles of 35° only) (*see* fig. 4).

AIRPLANES.

The method of restitution of the photographs which is used assumes that the photographs of the same strip overlap more than 50 % and that the optical axis of the camera is only slightly inclined to the vertical. This result can only be obtained by a skilful pilot ; trials of gyroscopic stabilisation have not been successful. It is no easy matter to keep at a constant altitude — and avoid accelerations — and to maintain a prescribed course. The pilot must make full use of the compass and of speed and turn indicators.

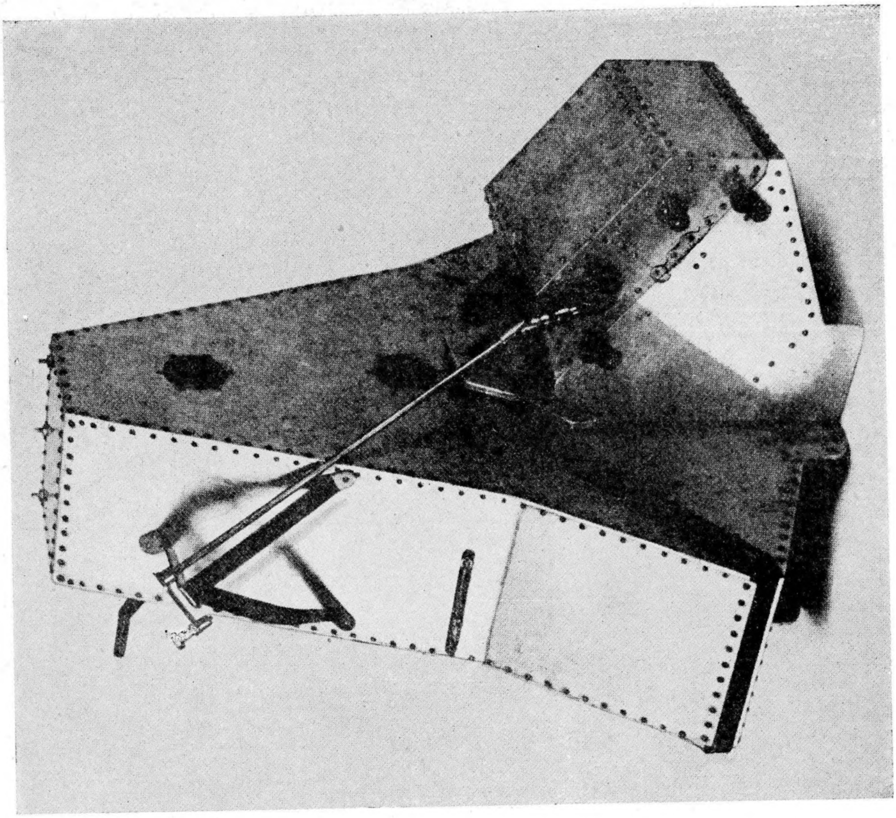

FIG. 2. — *Improvised four chamber camera.*
Appareil expérimental à 4 plaques

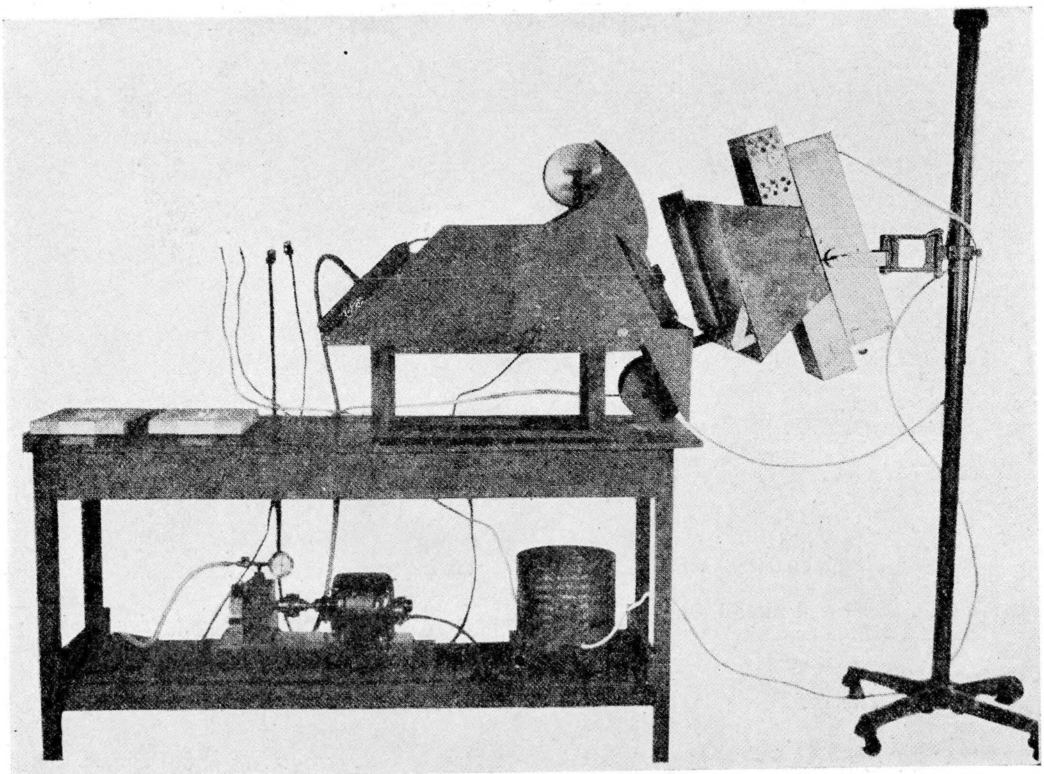

FIG. 4. — *Transforming Printer.*
Tireuse de Redressement.

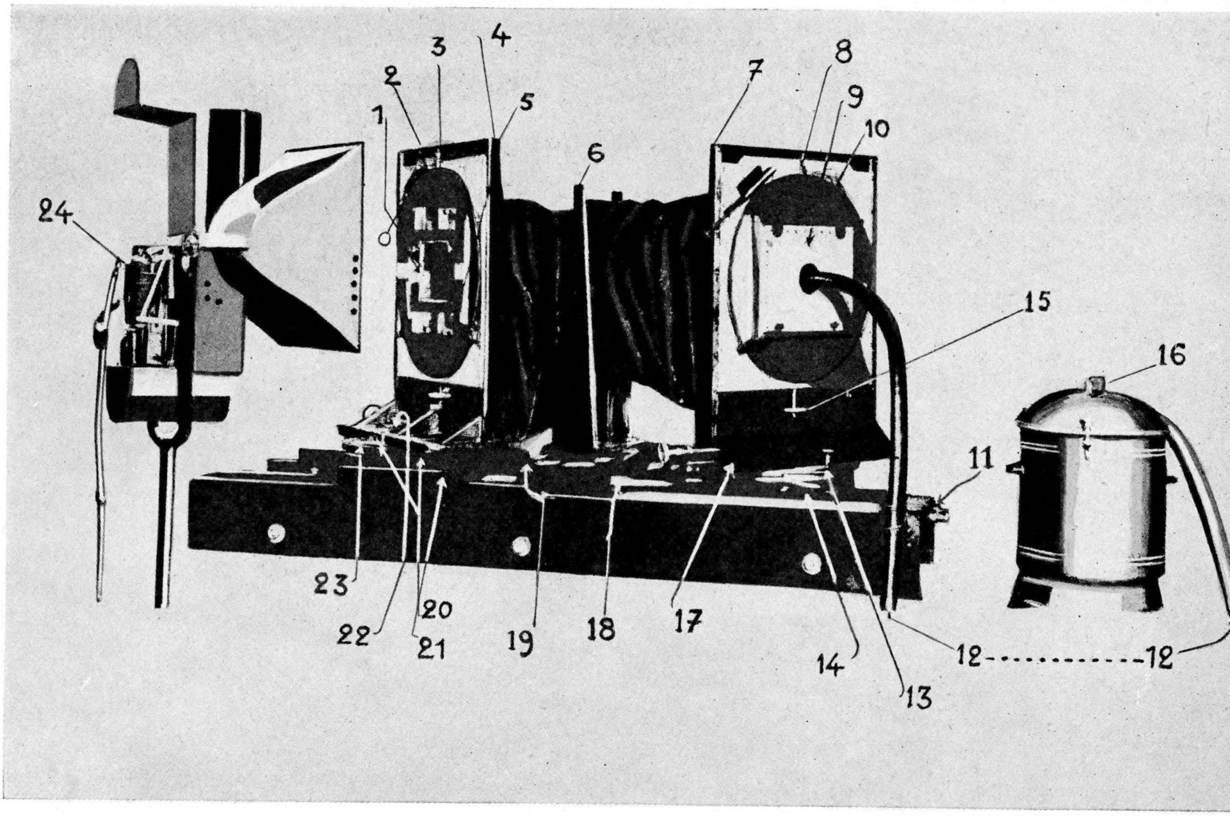

FIG. 3. — *Moffit Photographic Transformer.*
Appareil Photographique de Redressement Moffit

1 Negative kit.
Emplacement support du négatif.

2 Negative disk.
Disque du négatif.

3 Index for negative disk.
Index du disque du négatif.

4 Negative standard.
Cadre du négatif.

5 Screws for adjusting negative kit.
Vis pour régler le support du négatif.

6 Lens standard.
Cadre de la lentille.

7 Image standard.
Cadre de l'image.

8 Index for image disk.
Index du disque de l'image.

9 Vacuum paper and plate holder.
Chassis à vide pour tenir le papier et le cliché.

10 Image disk.
Disque de l'image.

11 Crank screws.
Manivelle de la vis sans fin.

12 Tube connecting pump to vacuum holder.
Tuyau reliant la pompe au châssis aspirateur à vide

13 Angle graduated arc and vernier.
Vernier et limbe divisé de l'angle.

14 Image scale opposite this on reverse side.
Echelle de l'image (par derrière).

15 Vertical screw.
Vis verticale.

16 Vacuum pump.
Pompe à vide.

17 Adjusting scale.
Echelle de réglage.

18 Alignment slotted bar.
Engoujure de centrage.

19 Base tracks.
Chemins de roulement.

20 Capstan screws (hidden).
Vis à papillon (cachées).

21 Negative scale opposite this on reverse side.
Echelle du négatif (par derrière).

22 Offset scale (not visible).
Echelle de compensation (pas visible).

23 Angle *B* gratuated arc and vernier.
Vernier et limbe divisé de l'angle *B*.

24 M' Beth arc light.
Lampe à arc M'Beth.

A special design of aircraft is used. The Army Air Service employs the De Haviland aeroplane, which will be replaced by the 0-2 Douglas Observation plane, which has a speed of 120 miles (222 kil.), a ceiling of 18,000 feet (5,400 m.) and a cruising radius of 800 miles (1500 kil.). The Navy Department uses a Loening Amphibian *OL* 2 planes which has a maximum speed of 121 miles (224 kil.) per hour. — a ceiling of 11,300 feet (3,400 m.) and a cruising radius of 405 miles (750 kil.) The Amphibian type has many qualities that make it suitable for this kind of work.

As a result of two years experience, it has been found that 80 % of the photographs taken by a good pilot have a tilt of less than 1° — that less than 5 % are tilted more than 2°, and that a tilt of 3° is rare. Moreover, changes of elevation of the airplane will not greatly exceed 100 feet (30 m.) in flights over flat or rolling country. It has been found advantageous to fix on the cameras, bubble levels, the position of which is photographed at the moment of taking; it is an acknowledged fact that whenever the tilt does not reach 1° the readings of the levels are correct. They are incorrect only 5 times in 100, and then by means of the high values reached by the tilt indicated those photographs which require big corrections are known.

METHOD.

The method which is about to be described rests on the graphical determination of a great number of secondary control points. It can be applied only if the inclination of the optical axis is very slight (as a rule less than 2°) and if the relief of the ground does not exceed a few hundred feet (100 m.). It will be admitted that distortions caused on the photograph by tilt and relief of the ground are produced along the lines which join the points to the centres of the photographs. These could then be treated as a plane table, on which the stations are made at the centre of the photographs, and those bearings only would be used which radiate from these centres.

Photographs taken by a multi-lens camera (composite photographs) have the disadvantage that the points situated near the outer edges would be fixed by lines which intersect at small angles.

This could be remedied if several parallel strips of photographs partially overlapped.

It is always necessary to determine by ordinary methods the position of a number of primary control points, at least equal to those which would be necessary for an ordinary survey. They should preferably be distributed in such a manner as to form a circuit around the photographed area, and besides [for an area of 15 miles (28 kil.)] two intermediate lines of points at right angles to the direction of flight, thus dividing the area into three approximately equal parts.

For the secondary control points, at least nine points are selected and distributed near the corners, the middles of the sides and the centre. Each group of three of these points approximately aligned at right angles to the line of flight, will be found on three successive photographs, where they should be easily recognised. Those points which are near the centre of photographs should be chosen to lie as near as possible to lines connecting the centres of photographs. They should assist in determining the centre of the intermediate photograph on those which precede and follow; they might well be the centre itself if it is easily recognisable.

Points must also be chosen which will serve to link up the successive strips of photographs. It has been found that it is preferable that these strips should overlap a little more than 50 %. It will be sufficient to have one connecting point, for each side, in every 3 or 4 photographs, and it should be included in at least 2 photographs of each series that overlap. All these points should be carefully surrounded by a small circle on the photographs and numbered.

In order to transfer the net of secondary control points, a sheet of celluloid is used, which is more suitable than tracing paper or cloth. These sheets which are 02 m/m (0.008 ins) thick are obtained commercially in rolls of 1 metre (40 ins) in breadth and 30 metres (100 feet) and more in length. They cost 0.20 dollars per square foot (about 55 francs per square metre). They can be used several times — as the ink can be removed with a wet rag. It should be remembered that they contract a little in drying after some days of exposure to air.

Taking as a provisional base on this celluloid sheet, a line equal to that which joins the points near the centre of the first photograph to those near the centre of the second, the positions of the control points common to the first two photographs are determined by the intersection of lines radiating from each centre. Next the position of the centre of the third photograph may be fixed which should be such that the lines joining this centre to the three points common with the first photograph pass through the positions which have been adopted for these points and be also on the line already provided by the second photograph.

In this way the fixing of the net of secondary control points may be continued. Each of them, except the first, will be fixed by the intersection of three straight lines, which should cut at the same point, if the plotting has been accurate, and if the assumed hypothesis of slight tilt and low relief is correct.

By this method as many conspicuous points can be fixed as desired, except those which are situated near the line of flight, which can be plotted by means of the adjacent parallel strip.

With the tri-lens camera the number of these strips can be reduced.

In the same manner, after having carefully circled them in on the photographs the primary control points whose position has been located on the ground can be fixed.

As far as possible, not more than 10 or 12 photographs should be taken between two primary control points. The distance between them will permit the scale of the secondary control net to be corrected, either by photographing it or with the pantograph.

Zinc or aluminium plates, grained as for lithography, have been adopted to transfer the net thus corrected and to make the detailed adjustment of the various strips, in view of drawing the chart.

Altitudes are obtained also by means of photographs and the contour lines are drawn. The best conditions for their exact determination are those of the points situated on the outer edges of oblique photographs taken with multi-lens cameras. Errors did not exceed 2 to 6 m. (7 to 20 feet) with a tri-lens camera giving photographs on a scale of $\frac{1}{30,000}$.

Great Britain has sent to the International Hydrographic Bureau some new publications of the Air Survey Committee:

(a) *Simple methods of surveying from Air photographs*, by Lieutenant HOTINE, R. E. - London, 1927 - professional paper N° 3.

(b) *Flying for Air Survey photography*, by F. TYMMS, M. C., A.F.R. Ae. S., and Flight-Lieutenant C. PORRI, R.A.F., members of the Air Survey Committee - London, 1927.

(c) *The Stereoscopic Examination of Air Photographs*, by Lieutenant M. HOTINE, R. E., - professional paper N° 4 - London, 1927.

In the first of these documents, a method of using air photographs is explained which is similar to that just described in the preceding pages. However, as it presents certain differences resulting from a very great endeavour to obtain accurate results and from ground which appears to be more hilly than that where the U. S. Aircraft had applied it, it appears useful to make some further remarks.

The survey was carried out in the vicinity of Arundel, of which there is already a chart on a scale of six inches to one Statute Mile. It has been possible to construct a chart on the same scale and to compare the results. These are very satisfactory and prove that the method can be employed with economy in time and cost for the construction of charts on scales smaller than $\frac{1}{10,000}$. It is simple, rapid, and does not necessitate the use of costly restitution apparatus and appears to be of particular interest to the hydrographic worker who has to carry out a survey of a coast, along which it has been possible to take strips of photographs from an aeroplane.

The method is not absolutely accurate; it should be attempted and applied only if the following conditions are fulfilled. The photographs of any one strip should be taken each with an overlap of 60 % by an expert pilot who should fly at as constant a height as possible, keep a straight course and maintain the optical axis of the camera within at least 2° of the vertical.

A small number of points, fixed by triangulation, will allow the scale and the orientation to be decided and determine whether the desired accuracy has been obtained.

In the publication *Flying for Air Survey Photography* 1926, the best methods of flight are discussed and also the sighting appliances used to ensure a straight line of flight; also the method of maintaining the verticality of the optical axis and for ensuring the overlap.

Turns should be absolutely forbidden because they cause a deviation from the vertical. For photographing a coast, it must be divided into rectilinear sections, the passage from one section to another being effected by a manœuvre which brings the aeroplane back over the previous section in such a way that it may be steadied on the new course before the camera is again brought into use over the new section.

METHOD.

The process of restitution is based on the following principles:—

(*a*) The tilt of the plate does not modify the angles emanating from the centre of homology or isocentre, *I*.

(*b*) Verticals are projected on the plate along lines the prolongations of which always pass through the same point *V*, the meeting point of the plate and of the vertical of the optical centre.

These points *I* and *V* lie on the line of maximum slope which passes through the principal point *P* of the plate and are at distances from *P* of $f \tan \frac{\theta}{2}$ and $f \tan \theta$ (where f is the focal length and θ the inclination of the optical axis to the vertical). If the tilt θ can be prevented from exceeding 2° it can be assumed, as a first approximation, that the points *I* and *V* coincide with the point *P* which can thus be used in their place, except for the restitution of those points which are near the centre. The point *P* is marked on the plate, whilst the points *I* and *V* are not known.

RESTITUTION OF SECONDARY CONTROL POINTS.

On each photograph six clearly defined points are selected (2 only on the first and last, 4 on the second and on the one before the last) which are respectively near the four corners and in the middles of the sides of the plate which are parallel to the direction of flight.

Owing to the overlap of more than 50 % these six points are found on successive photographs as also is that which corresponds to the centre of the photograph.

A stereoscope may be used if necessary for the definite identification of these points, which are called secondary control points. In accordance with the principles given above, the displacement of their images caused by the tilt of the plate, the altitude of the points and the variation in height of the aeroplane, takes place along radial lines passing through the centre *P* of the plate.

Taking then as base the distance between the centre of the first plate and one of the points selected in one of its corners, a kind of double photographic triangulation can be made graphically along the strip the apices of which correspond to the secondary control points, and will be determined generally by 3 lines of intersection. If, in spite of all the care that has been taken in plotting, these lines of intersection do not meet at the same point, a consideration of the problem will determine the most probable position to adopt. Experiene has shown that the triangle of error is always very small, and that the choice of position in the interior of the triangle can always be made by eye.

The broken line obtained by joining the restituted positions of the centres of the successive photographs permits the value of the flight to be judged. If the points are not spaced equally, there has been a variation in the ground speed or in the fore and aft tilt. The fact that the points are not in a straight line, is due to a change of wind or to the line of flight being badly kept, but more often to a lateral tilt.

CONTROL TRIANGULATION.

It is necessary for the purpose of fixing the scale and the orientation of the preceding restitution and to prevent accumulations of errors, to determine by ordinary methods the position on the ground of a certain number of points. Others would also have to be specially fixed in regions where the overlap of the photographs has not been sufficient, in the more hilly districts and in those where a pronounced lateral tilt is found.

It therefore seemed necessary to fix a point at about every three to four miles to survey the Arundel region for a chart on a scale of three inches to the mile. These trigonometrical points, carefully identified on the photographs, are plotted by the same method as the secondary control points.

RESTITUTION OF THE DETAILS.

The net should be traced on a celluloid sheet, prepared in such a way that a drawing can be made on it in ink. The necessary details of a photograph, previously centered and oriented, are inserted in blue ink. Then this photograph is replaced by one of those which overlap it, and the insertion of the details in black ink is continued, based on the principle that, if two photographs provide two slightly differing positions for any one point of these details, that point should be inserted by eye at the intersection of the radial lines joining these positions to the centre of each photograph. If these bearings are nearly the same the distance of the two positions thus obtained should be divided in proportion to the distance of each position from the centre of the relevant photograph.

Near the centre of the photographs the details may, as a rule, be entered without alteration.

The taking of a second strip of photographs, parallel to the first and partly overlapping it, will not generally be necessary for coastal surveys, which concern hydrographic charts. A check of but little value, in the part common to the first and second strips, would be obtained, for these two strips are difficult to compare because of the inevitable difference in altitude of the flights, of the irregularity of overlap and of variation of tilt. When once the tracing of the details on the celluloid is finished, the different portions between the points of the control triangulation are photographed to the exact scale desired and a definite draft is made.

A good length for the distance between two points of the control triangulation is from 5 to 13 kiloms (3 to 8 stat. miles) according to the nature of the ground. If the points are nearer, it is not necessary on that account to make a greater number of photographic adjustments. The final drawing can usually be very easily fitted on to the supplementary points by eye.

REMARKS.

A good pilot, in favourable weather, becomes proficient in the regularity of his flight and in preventing too great a tilt of the optical axis. Attempts are being made to maintain a constant tilt by means of gyroscopes; accurate results have not yet been obtained. The addition of very sensitive levels will not show the errors in the vertical which are most dangerous, namely, those which are due to acceleration.

For hydrographic surveys, in which the exact representation of the relief of the ground is less necessary than the accuracy of positions, it is advantageous to fly at a great height using a lens of focal length suitable for the desired scale. Moreover, the photographs are capable of being enlarged to approximately three times their original size without losing their accuracy and it is better to have recourse to this expedient than to fly lower or to employ a lens of greater focal length, for it is of great importance not to augment the number of photographs. However, in order that photographs may be properly interpreted, the scale should not generally be less than $\frac{1}{30,000}$.

SHORT OVERLAP.

It is almost inevitable that some photographs will have an insufficient overlap. In such a case the best thing to do is to fix a point on the ground to take the place of the control due to the overlap.

Otherwise the following procedure must be followed: The position on a photograph of the centre of the adjacent photograph can be marked even if the overlap is insufficient for it to be shown, a stereoscope will serve for this purpose; but it is evident that the accuracy will be less as the overlap diminishes. The orientation of the photographs can be determined thus: If A on the photograph P_1, the centre of which is p_1, is the last control point obtained from the photographic chain and if this point is not found on the following photograph P_2 because of short overlap, a point a as near as possible to A should be chosen, which should be, as far as possible, at the same stereoscopic depth as A. If A' is the plotted position of A, the position of the point a' on the line $p_1\ a$ would be adopted, so that

$$\frac{p_1 A'}{p_1 A} = \frac{p_1 a'}{p_1 a}$$

The chain could then be continued as above.

STEREOSCOPIC EXAMINATION.

Publication N° 4 is preceded by a preface by Colonel H. St. J. L. WINTERBOTHAM, President of the Air Survey Commission. He remarks on the importance of the stereoscopic examination of photographs and shows how difficult is the study of this subject, which depends both on the brain and on the astonishing adaptability of the human eye.

This delicate question is treated in a very precise and complete manner. It contains a theoretical study giving the necessary rules for stereoscopic examination, rules which are sometimes neglected by some operators and which, if ignored, lead to the deduction of inaccurate results from a method which, otherwise, is capable of giving valuable data.

Strictly it is necessary that the photographs and the view points occupy relative positions identical to those at the moment of exposure: except that the distance which separates the view points can be modified as desired, causing at the same time a proportional modification in the scale of the stereoscopic image.

From this necessary and sufficient condition it results that, in order to examine two photographs in the same plane with an ordinary stereoscope, they must previously be set in a plane which is parallel to the base formed by the line joining the two view points, and not in a horizontal plane if this base is not horizontal.

Incidentally an interesting principle is mentioned used by H. C. FOURCADE in the construction of a Stereogoniometer: it is sufficient, in order to place two photographs in their correct positions relative to each other for stereoscopic examination, that 5 points thereon be recognised (See: "*Transactions of the Royal Society of South Africa* 1926 *and* 19*th October* 1927, *A New Metod of Aerial Surveying*"). Thanks to this method, it is sufficient that in a photographic strip the position of one of the photographs be known, for the positions of all the others to be deduced and for all to be transformed in the same plane.

More or less important changes, sometimes negligible, which result from an incorrect setting of the photographs are studied in detail; the means of calculating the focal length of the lenses which can be suitably employed in the stereoscope are indicated to ensure a good accommodation of the binocular vision, taking into account the overlap of the prints, the height of the aeroplane and differences of altitude between the points photographed. The study, from this point of view, of tilted photographs leads to the conclusion that it is expedient that the optical axis be perpendicular to the mean slope of the ground. Thus this axis should be vertical to photograph a flat or slightly undulating surface but to photograph the slopes of a mountain range, the flight should be parallel to the range, and the plates so arranged that they would be practically parallel to the average slope of the range.

For a qualitative examination of the relief of a small area, the theoretically indispensable precautions which have been described may be neglected without much disadvantage, but the more exact the measurements required and the larger the area, the more necessary it is to apply them. Moreover, absolute measurements can only be obtained from comparison with the heights of control points fixed on the ground.

A net work or parallactic grid, consisting of lines equally inclined with reference to the line joining the view points is etched on glass and superimposed over the photographic prints. When the ground is not very hilly, this net work permits the existence of tilts either of the base or of the photographs to be recognised. Trough unable to distinguish between these two sorts of tilts, it will show the quality of the flight.

Examination with an ordinary stereoscope and a grid, of a flat surface the photographs of which have only a slight tilt, will give the illusion that the ground rises in a reverse direction to the tilt of the photographs and will allow the point on the ground where they are met by the verticals from the optical centres to be fixed approximately.

Floating marks (sort of indices) arranged above each print are frequently placed in stereoscopes. They become one by binocular vision, appearing to float in space, and may be made to recede from or lie on the ground by varying the distance of the two corresponding indices or of the two photographs. Their use brings the study of absolute altitudes to that of relative measurements. Certain types of index are preferable for this examination.

The Air Survey uses mostly the Topographical Stereoscope by Barr and Stroud, which is constructed on the principle of the Wheatstone Mirror Stereoscope. It permits the examination of photographs over a large surface. It is furnished with parallactic grids, in close contact with the photographs. They can be made to slide, to swing clear or to be brought nearer by amounts, measured by a scale, of about a 10th of a millimetre. A micrometer of greater accuracy seemed needless for examining proofs which have undergone distortion and are not capable of giving great accuracy. The grids permit the measurement of differences of parallax, which are directly proportional to the differences of height if the photographs are but very slightly tilted. Under good conditions, and with well defined points, differences of 3 metres (10 feet) can be appreciated.

Much practice and topographical experience is necessary to trace contour lines properly.

It is advisable to join the points the heights of which are known, by a black ink form line. These form lines are lines of uniform and known declivity.

By comparing them with the neighbouring ground, the various intervening heights can be filled in, and the drawing of the contour lines completed by eye according to the general sense of the relief.

We have only been able to give a rapid review of the methods, limiting ourselves to those which are of special interest to Hydrographic surveys. Mention is made in the publications of many details and precautions which are very useful when conducting flights and delicate graphical operations, in order to prevent long and repeated trials and to develope the stereoscopic sense.

Advice is also given for constructing mosaics as accurate as an arrangement of photographs can be which, owing to differences of altitude, cannot be completely continuous. It is necessary also to consult the following publications of the Air Survey Committee :—

N° 1. — *Graphical Methods of Plotting from Air Photographs*, Lieutenant Colonel L.N.F.I. King, O.B.E., R.E., London.

as well as "*Aerial Surveying by Rapid Methods*", by Professor MELVILLE JONES.