SURVEY OF INDIA

PROFESSIONAL PAPER No. 24.

NOTES ON AIR SURVEY IN INDIA

BY

MAJOR W. J. NORMAN, M.C., R.E.

PUBLISHED BY ORDER OF
BRIGADIER R. H. THOMAS, D.S.O.
SURVEYOR GENERAL OF INDIA

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FOREWORD

These notes are written mainly for the use of survey officers who have had little practical experience of air survey and have not had time to study the literature on the subject.

It is not an exhaustive treatise, but a review of the general principles of air survey, with brief notes on various methods employed, and references to books in which further technical details are given. The methods described practically all deal with mapping from vertical photographs.

The science has developed very recently; new methods are continually under investigation and trial, and it is difficult to keep up to date.

SECTION I

INTRODUCTION

1. *Preparation of a project.*—Any air survey project comprises the following operations:—

(*a*) Fixing control,
(*b*) Flying and photography,
(*c*) Compilation,
(*d*) Reproduction.

Before the project can be worked out definite decisions must be made on:—

(*i*) the purpose of the survey,
(*ii*) the form of the final map, i.e. scale, number of copies etc.,
(*iii*) the accuracy required,
(*iv*) the area to be covered,
(*v*) time and money available.

Detailed plans must then be worked out for each of the component operations, treating the project as a whole; each separate operation reacts on the others and the methods employed on each should be such as to give the required results most economically.

2. *Steps in a project.*—The *control* usually takes the form of theodolite triangulation or traverse, and should be the minimum to give the necessary accuracy, but sufficient to give economical flying and compilation.

The *photography* should be worked from a suitable centre: and be carried out with minimum flying time and minimum expenditure of photo material; but should be sufficient for economical and accurate compilation.

The photography must be carried out on a definite plan to fit on to the control.

The *compilation* includes interpretation of the detail on the photographs, reducing it to correct scale, and placing it in its correct position on an original, ready for reproduction. Drawing and photography must be kept to a minimum for economy both of labour and material.

The compilation should be a true representation of the ground just as a plane-table section is. It may be necessary to make a fair drawing or tracing for reproduction, but it is better to complete the compilation in such a way that it is fit for direct reproduction.

3. *Points which require careful consideration* and consultation between the officers responsible for ground control, photography, compilation, and the officer or department for whom the map is being prepared, are:—

(*i*) The lay-out of the *control.*

(*ii*) The distance apart of the fixed points.

(*iii*) The method of selecting the points, and marking them on the ground, if this is required.

(*iv*) The stage at which the control shall be fixed.

(*v*) The scale on which the *photographs* shall be taken; this being controlled by the focal length of the camera and the height of flying.

(*vi*) The lay-out of the strips of photographs, so as to ensure adequate tying down by ground control and the complete covering of the area.

(*vii*) The amount of overlap to be allowed between photographs, both fore-and-aft and lateral.

(*viii*) The dates between which photography should be completed. It reduces costs immensely if flying can be fitted in with other work in the neighbourhood, so as to reduce transport charges and unproductive moves.

(*ix*) The time of day when lighting will be most suitable for the objects of the survey.

(*x*) The method by which supplementary ground work, such as survey of concealed detail and boundaries, and collection of names, shall be carried out.

(*xi*) The stage at which this ground work will be carried out.

(*xii*) The exact details of the methods by which *compilation* shall be carried out. These depend on the closeness and lay out of the control, the accuracy of the flying, the purposes and scale of the survey, and the form in which it is to be reproduced.

Much will depend on the staff available, and it is essential for economical work that the officers and draughtsmen employed shall be well trained in such methods as are adopted.

(*xiii*) The standard of accuracy to be maintained in the various steps of compilation: the methods to be adopted to ensure these standards are maintained: the officer responsible for examination.

(*xiv*) The location of the compiling office. It is not necessary that compilation should be carried out near the ground, but there should be close liaison between the officers in charge of ground control, flying, and compilation, while work is in progress, and also between the officer in charge of the compilation and the officer for whom the survey is being carried out.

(*xv*) The final testing of the work on the ground. This should be carried out by an agency, and to a standard, to be settled beforehand.

(*xvi*) The *reproduction* of the maps required. This may be by any methods suitable for ordinary maps; but it is important to decide beforehand the scale, size, and lay out of the printed sheets; for the scale and lay out of the compilation sheets depend on these.

(*xvii*) Detailed estimates of cost must be taken out for each operation.

(*xviii*) The limits of responsibility between the various officers engaged on the work.

4. *Considerations affecting cost.*—Cost rates for air survey are at present unduly high, while methods are still under experiment and personnel under training.

Air photography is very rapidly carried out: a flight of two machines could photograph 10,000 to 20,000 square miles a year. Air survey companies have therefore to make provision for large overhead charges due to the cost of moves from one job to another and to the fact that personnel and machines are often idle between one job and the next.

5. *The cost of flying* is as a rule the largest item in the cost of air survey.

It is now more or less possible to calculate the area which should be photographed per flying hour, given certain instruments and trained personnel.

This area per flying hour varies from about 5 to 150 square miles, depending on the scale of photography and the type of camera used.

The cost of an hour's flying is somewhere between £ 10 and £ 30 (Rs. 130-400).

The lowest rate given for the cost of flying and photography is $ 3 (Rs. 8/-) per square mile in America. This is for photos of large areas on about 1/20,000 scale taken with the tri-lens camera.

In England for a similar scale but for work of very small areas £ 5 (Rs. 66/-) a square mile has been quoted.

The rate in the Irrawaddy Delta survey was Rs. 210/- per square mile, for 3-inch forest survey.

A private company has obtained a contract for photography for surveys on small scales of large areas in Rhodesia @ £ 5 (Rs. 66/-) per square mile.

The estimated cost of ¼-inch survey of Rhodesia using oblique photographs is about Rs. 20/- per square mile.

6. *Cost of ground control and compilation* are also hard to estimate.

The cost of the ground control depends on the scale of the map, the nature of the country and the cost of transport. This should be less than the cost of fixing ground control for plane-tablers working on the same scale, as the fixed points required may be fewer.

The cost of compilation depends on the methods used, the scale of the map and the amount of detail to be shown.

For the Irrawaddy Delta forest survey on the 4-inch scale the cost of compilation and mapping was Rs. 26/- per square mile (Rs. 16/- compilation and Rs. 10/- mapping).

For the Arundel experiment, the cost of compilation of a topo map of undulating country on the 1/20,000 scale was 15 shillings (Rs. 10/-) per square mile.

For the Chittagong Forest Surveys on the 4-inch scale, the cost of compilation without fair mapping was about Rs. 15/- per square mile.

Experience in No. 18 Party indicates that the cost of compilation of large scale settlement maps by rectification of individual photographs will be Rs. 30/- to Rs. 60/- per square mile.

7. *Economic use of air survey.*—Air survey should as a rule be cheaper than ground survey for scales from 3 to 16 inches to the mile.

In the U.S.A. where three years ago the Coast and Geodetic Survey were doing 40% of their annual topo programme by air survey, (the government air service supplying the photos) it was estimated that air survey saved up to 50% (average 25%) in the cost of original topo surveys and 75% in the case of revision.

The cost of settlement surveys now being carried out in Bengal and the U.P. by the Air Survey Company who are themselves doing the compilation, is between Rs. 140/- and Rs. 250/- per square mile.

SECTION II

THEORY AND GEOMETRY OF AIR SURVEY

8. *Definitions.*—An outline of the main principles will be given here. Full details can be found in:—

> "Graphical Methods of Plotting from Air Photographs" by Lt-Col. L.N.F.I. King, O.B.E., R.E., Professional Paper No. 1 of the Air Survey Committee, published by the War Office, 1925.

Full definitions of air survey terms are given in this publication. The following are brief explanations of the more important.

Optical Axis.—The line joining the nodal points of the lens system.

Vertical Photo.—An air photo taken with the optical axis vertical or nearly vertical.

Oblique Photo.—An air photo taken with the optical axis distinctly oblique.

Air Position.—The position of the camera lens in space at the moment of exposure.

Tilt.—The deviation of the optical axis from the vertical. Tilt may be "fore-and-aft" tilt when the axis of tilt is at right angles to the line of flight of the aeroplane or "lateral" tilt when the axis of tilt is parallel to the line of flight, or a combination of these two.

Collimating Point.— A fine mark, fixed to the camera body, which is photographed on all plates or films exposed.

Plate Axes.—The lines joining opposite pairs of collimating points on the photographic plate.

Plate Perpendicular.—The perpendicular from the lens upon the photographic plate. (This perpendicular is taken from the rear nodal point of the lens).

Principal Distance.—The length of the above perpendicular. (This is the focal length of the lens when the plate is in the focal plane).

Principal Point.—The foot of the above perpendicular.

Plate Centre.—The intersection of the plate axes.

Optical Centre of plate.—The point where the optical axis of the lens cuts the plane of the plate.

In a perfectly constructed camera the last three points would coincide.

Axis of Tilt.—That horizontal line on the photograph which passes through the principal point.

Plumb Line.—A true vertical line through the lens of the camera.

Principal Plane.—The plane which contains the plumb line and the plate perpendicular.

Principal Line.—The trace of the principal plane upon the photograph.

Plane of Reference.—That plane to which the planimetry and relief of an air photograph are primarily referred.

Plate Plumb Point.—The point where the plumb line cuts the plane of the photograph.

Map Plumb Point.—The point where the plumb line cuts the plane of the map.

Ground Plumb Point.—The point where the plumb line meets the plane of reference.

Isocentre.—A point, approximately midway between the plate plumb point and the principal point, at which the angle subtended by any two points that are the images of objects lying in the plane of reference is preserved unaltered from nature.

Rectification.—The process of converting the projection on a tilted plane to that of any chosen plane of reference.

Mosaic.—An assemblage of photographs fitted together to form a combined picture.

A mosaic may be "uncontrolled" when the photos are joined together with no reference to fixed points or other surveys: or "controlled" when the position of detail on the mosaic is made to agree with other surveys or with some points fixed by ground survey.

A mosaic may be made from either rectified or unrectified photos.

Overlap.—(1) A general term implying that the photographs of a strip or mosaic partly cover their neighbours; (2) in an assemblage of photographs, the proportion of the length or width which is common to two successive photos. Measured in the direction of travel it is defined as "forward" overlap; measured at right angles to the direction of travel as "lateral" overlap.

Calibration of a Camera.—Finding the camera constants i.e.

Principal Distance,

Principal Point,

Plate Centre,

Optical Centre of Plate.

The position of these 3 points is defined relative to the collimating points fixed to the camera body.

Detailed instruments for calibrating a camera will be found in Professional Paper No. 5 of the War Office Air Survey Committee.

9. *The Camera.*—Consider the case of a truly vertical photograph of flat country taken with a perfect camera, as depicted in figure 1.

XY represents the maximum dimension (i.e. diagonal) of the plate in the camera.

L represents the lens.

AB represents the portion of the ground photographed.

H is the height of the camera above ground.

f is the focal length of the camera lens.

U & W are any two points on the ground.

U^1 & W^1 are the images of these two points on the photograph.

The scale of the photo is $\frac{U^1W^1}{UW} = \frac{f}{H}$

The length of AB i.e. the amount photographed $= \frac{XY \times H}{f}$

If the angle subtended by AB at L be $2a$ then $\tan a = \frac{XY}{2f}$

This angle ($2a$) should be less than the covering power of the lens. This covering power varies with the make of lens and is usually less than 60°. If the size of the plate be unduly increased in proportion to the focal length of the lens, the photos will be blurred or distorted at the edges.

Distortion of the photo *in the camera* may be due to any of the following:—

(*a*) Defects of the lens.

(*b*) Axis of the lens not perpendicular to the plane of the plate or film.

(*c*) Use of focal plane shutter. With a small slit the exposure may be 1/250 second but this slit may take 1/10 second to cover the plate. During this time the aeroplane may have covered 12 to 15 feet. So that if the shutter travels parallel to the line of flight the scale of the photo will be drawn out or compressed in that direction or, if the shutter works transversely, detail along one edge of the photo will lag behind its true position.

(*d*) Plate or film not being exactly in the focal plane.

Any camera used for air survey should be carefully made and accurately calibrated, i.e. the principal point and the optical centre should coincide. The position of this point as well as the principal distance should be accurately determined, the former with reference to the plate centre.

The position of the principal point is known with regard to the collimating points. A templet can therefore be made for use with all photos taken from one camera. This templet is fitted on the images of the collimating points on the photo and the position of the principal point pricked through.

10. *The effect of relief.*—Next consider a truly vertical photograph of country which is not flat, as in figure 2.

L is the lens of the camera.

Let U and W be two points on the surface of the ground at distance H_u below and H_w above the plane of reference.

Let U′ and W′ be their positions in plan on the plane of reference.

Rays from L to U and W intersect the plane of reference at X and Y.

Let H be the height of the camera above the plane of reference.

V′ is the projection on the plane of reference of the ground plumb point V.

It is clearly seen that, to the camera, U will appear at X and W will appear at Y, whereas their true positions on the plane of reference are U′ and W′.

The distortions of the 2 points are U′ X and W′ Y

or $\frac{V X \times H_u}{H}$ and $\frac{V Y \times H_w}{H}$

This shows that the distortion is inwards towards the plumb point for points below the plane of reference, and outwards from the plumb point for points above the plane of reference; also that this distortion varies as the distance of the point from the plumb point and the height of the point above or below the plane of reference.

There is no way of eliminating this distortion due to relief. If a lens of long focal length be used the distortion is reduced, but flying time and cost of photographic materials will be increased.

It should be possible, knowing the height of the aeroplane, to calculate the height of any point by measuring its displacement and distance from the plumb point. The air photo is, however, subject to so many errors that this is only an exact method if very elaborate and therefore expensive processes are used.

It is this displacement, however, which enables relative relief to be seen in a stereoscope.

It is clear from the diagram that this distortion due to relief is quite independent of any tilt on the camera and is radial from the ground plumb point vertically below the lens.

11. *The effect of tilt of the camera.*—Next consider the case of a tilted "vertical" photo of flat country.

Figure 3 is taken in the principal plane of a tilted photo.

L is the lens.

f is the focal length of the camera.

H is the height of the camera above the ground.

P is the principal point and P P_G the principal line.

V is the plate plumb point and V_G the ground plumb point.

I is the isocentre.

X_G is any point on the ground and in the principal plane and X its image on the plate.

The ray L X makes an angle of β with the principal line.

The tilt of the camera is θ.

If the photograph had not been tilted its scale would have been $\frac{f}{H}$.

Take a point D on the principal line so that L D = H = L V_G.

Through D draw E D F perpendicular to L D.

The scale of the photograph of any object on the line E D F will be $\frac{f}{LD} = \frac{f}{H}$.

The line E D F intersects the ground line at I_G. The scale at I on the tilted photo is therefore the same as it would have been had the photo not been tilted.

It is obvious from the construction that L I bisects the angle P L V.

In the diagram, on the same side of I as the plumb point, the scale of the tilted photo will be larger than for the untilted photo: while on the same side of I as the principal point, the scale of the tilted photo will be less than for the untilted photo.

From X_G draw X_G K perpendicular to L P_G

then L X_G = H sec $(\theta + \beta)$,

and L K = L X_G cos β = H cos β sec $(\theta + \beta)$.

The scale of the photo at X is $\frac{f}{LK} = \frac{f}{H \cos\beta \sec(\theta+\beta)}$.

Through I draw a horizontal line. Let X′ be the point where the line X L cuts this line.

If an untilted photo had been taken at L, the distance of the image of X_G from I would have been I X′.

On the tilted photo the distance of the image of X from I is I X. By similar triangles,

$$\frac{IX}{IX'} = \frac{TX}{TL} = \frac{TI - IX}{TL}$$

$$TI = TL$$

$$\therefore \frac{IX}{IX'} = 1 - \frac{IX}{TL} = 1 - \frac{IX \sin\theta}{f}.$$

The displacement of the image of X due to tilt is

$$IX - IX' = IX\left[1 - \frac{f}{f - IX\sin\theta}\right].$$

Through X draw a line along the ground at right angles to the principal plane. Take any point Y on this line. Let the line I Y make an angle ϕ with the principal plane. (See figure 4).

The displacement of the image of Y due to tilt is

$$XX' \sec\phi = IX\left[I - \frac{f}{f - IX\sin\theta}\right]\sec\phi$$

$$= IY\left[I - \frac{f}{f - IY\sin\theta\cos\phi}\right]$$

12. *The amount and direction of tilt can be found* either geometrically or analytically, provided the co-ordinates of 3 points are known in addition to the camera constants ; or, if these latter are not known, provided the co-ordinates of 4 points are known.

Or the tilt relative to a second photo may be determined by the use of a stereoscope provided the height of four points are known as well as the height of the aeroplane, or by elimination of *want of correspondence*. (See para 19 under stereoscopy).

A tilted photograph may be rectified and an undistorted photo produced by the use of a rectifying lantern, a camera lucida or a epidiascope : or detail may be transferred to an undistorted plan by a system of squares.

For rectification in a lantern the plate holder, the lens and the copy board have to be correctly set relative to each other. This is nearly impossible to arrange by trial and error methods. Once the tilt is known, the lantern can be set quite easily and a rectified photo produced.

Figure 5 shows the effect of tilt on a photo.

A B C D is the undistorted figure.

V is the plumb point, P is the principal point, *I* is the isocentre.

P I V is the trace of the principal plane.

E I F is the line through I parallel to the axis of tilt.

A′B′C′D′ is the distorted figure due to tilt.

The figure is not distorted along the line E I F.

All points to the left of this line are moved inwards along rays from the isocentre and all points to the right are moved outwards.

Using a stereoscope, provided the heights of the points and of the aeroplane are known, it is possible to determine where the undistorted positions of the points should be. Lines joining the distorted positions of points to the undistorted positions meet at the isocentre, i.e. AA′, BB′, CC′, DD′, meet at I. When the isocentre is known, the tilt relative to the second photograph of the pair is also known. A description of the adjustments of a lantern, for the rectification of a negative taken at any angle of tilt, will be found in War Office pamphlet "Mapping from Air Photographs" by Lt. Col. MacLeod.

13. *The Radial Line Theory.*—Normally the tilt of a photo is not known and therefore the plumb point and isocentre are also unknown. The principal point, however, should always be known.

In the case of an untilted photograph the principal point, the plumb point and the isocentre will all coincide and all distortion will be radial from this point. Rays from the principal point will then be true and undistorted.

When a tilted photo is taken of hilly country the photo is distorted about both the plumb point and the isocentre.

Provided that tilts are not great, and that differences of relief are not large compared to the height of the aeroplane, the isocentre and plumb point will both be close to the principal point, distortions will not be large, and rays from the principal point will not be much in error.

If differences of relief are small, a comparatively large tilt (5°) will not seriously affect the rays from the principal point, but if differences of relief are large (10 % of the height of the aeroplane) a small tilt (1°) will have a considerable effect.

With differences of relief up to 3 % of the height of the aeroplane and with tilt up to 2° no appreciable error is introduced if a point is considered to lie somewhere on the ray joining its image to the principal point.

Plate 1 shows the distortion for points of height varying from 1 % to 10 % of the height of the aeroplane on a photo taken with a 10-inch lens and with a tilt of 3°.

If a strip of photos be taken with 60 % overlap as shown in figure 6 there will always be a portion in the centre of every photograph which is common to two other photographs. Two such common portions are shaded on the above diagram.

By drawing rays from the principal points of the first two photos, points can be fixed by intersection on any selected scale in the area common to Nos. 1, 2, 3 photos.

From these fixed points, the principal point of photo No. 3 can be located by resection.

Further points are fixed in the overlap of Nos. 2, 3, 4 photos by rays from the principal points of Nos. 2 and 3 photos and the principal point of No. 4 photo located by resection.

Thus a whole strip of photos can be joined together. (See para 42 for detailed description).

14. *Use of plumb point in radial line methods.*—When differences of relief are large and the photographs are at all tilted, rays from the principal point will be considerably in error, and it will be more accurate to use rays from the plumb point. The plumb point can only be found if tilt can be accurately determined.

An approximation to the plumb point may be used in preference to the principal point. This approximate position may be found by making an estimation of tilt under a stereoscope.

If the tilt however large can be accurately determined and the photographs rectified, the method is no longer approximate but is capable of giving work of the highest accuracy.

15. *Accurate measurements from photographs.*—There are two ways of making accurate measurements from a photo: such measurements may be required for calculating the camera position, tilt or the setting which will be required in a plotting machine. It is as well to remember that very accurate measurements can only be made on plates, never off films or prints.

The first method is to use a co-ordinatograph and to compute angles from linear distances. This is not very accurate as no allowance can be made for imperfections of the lens.

The second method is to use a photogoniometer.

This instrument consists of a camera, with the same (or exactly similar) lens to the one used when the photo was taken, the plate being placed in a corresponding position to that occupied in the original exposure; and a miniature theodolite mounted in front of it so that the axes of the theodolite pass through the front nodal point of the lens of the camera. With this instrument it is possible to measure the angles themselves.

16. *Stereoscopy.*—The intelligent use of a stereoscope is essential if the best use is to be made of air photos. It is therefore necessary to explain the theory of this instrument somewhat fully. For complete information on this subject Professional Paper No. 4 of the Air Survey Committee, "The Stereoscopic Examination of Air Photographs" by Lieut. M. Hotine, R. E., should be consulted.

When a person with normal eyesight, looks at an object, the angle of convergence of the two rays from his two eyes to the object, gives him an impression of the distance to that object.

It is possible by an optical instrument to increase the eye base from the normal 6 to 7 cm. to a considerably longer distance, and the convergence of the rays from the two eyes to any point is considerably increased, and relative distances are more easily appreciated.

It is possible to take a photograph at each end of the longer base, and to get the increased effect of distance by looking at each photo with the corresponding eye only.

When the two photos are thus looked at, the distance of the image of an object in one photo from the image of the same object in the other photo is a measure of "*parallax*", the greater this parallax, the further away the object appears with reference to any other object in the photos, whose parallax is less.

Any instrument in which two such photos are viewed is known as a "*Stereoscope*".

If the photos were reversed or interchanged and viewed by the opposite eyes, it is obvious that the parallax would be less for distant points. This means that these points would then appear nearest and near points would apear distant.

As this effect violates preconceived ideas, and as the scale of apparently near objects is less than that of far objects, many people are unable to visualise the reversed relief.

17. *Parallactic Grids.*—If a grid be placed opposite each eye, this grid will appear at a definite distance according to the parallax, and the greater the parallax, the further away it will appear.

If the grid be ruled on glass and placed on photographs, the grid viewed stereoscopically will give a plane at a definite distance, to which the distance of any object in the photograph can be compared.

The distance of the grid plane in space may be varied by altering the distance apart of the glass plates.

Such grids are called "*Parallactic grids*" and are used for contouring.

18. *Application of Stereoscopy.*—The principle of stereoscopic photography has been used for survey by several methods, all of which involve taking photographs of one area of ground from two different camera positions. The camera may be set up at two points on the ground or may be carried in an aeroplane.

When vertical air photographs are being taken from an aeroplane, an overlap of about 60 °/₀ between two succeeding photographs is allowed so that radial line methods can be used. The common portion of two succeeding photographs forms a stereoscopic pair, as they are taken from two separate positions of the aeroplane.

Owing to the great length of the optical base, i.e. the distance between two positions of the aeroplane from which succeeding photos were taken, the effect of relief is exaggerated and slopes appear much steeper than they are.

There are special stereoscopic plotting machines made, which automatically plot a map from such stereo-photographs.

19. *Setting photographs in a stereoscope.*—Before a pair of air photographs are looked at under a stereoscope, they ought to be set so that the plumb point base is parallel to the eye base, because the distortion due to relief, which produces the stereoscopic effect, is radial from the plumb points. As the plumb points are as a rule unknown it is usual to set the photographs by principal point bases. When tilts are small, using the principal point in place of the plumb point, makes little difference.

From the principal point of each photograph, a ray should be drawn that will pass through the principal point of the other photo. If the overlap of the photographs is more than 50 °/₀, this is easily done. If the overlap is less than 50 °/₀, the detail at the principal point of one photo will not appear on the other photograph. The principal point base is then found by rotating the photographs round their respective principal points till "*want of correspondence*" is eliminated along the principal point base (see next para).

When the principal point base has been found, the photographs are set in the stereoscope so that the principal point bases on the two photographs are in the same straight line and parallel to the eye base.

20. *Using distorted photographs in a stereoscope.*—If two photos are to be viewed stereoscopically without difficulty, they should have been exposed in the same plane. This condition is fulfilled in a perfectly taken strip of vertical photographs.

It may happen that although the planes in which the two photographs were taken are parallel they are not coincident e.g. two truly vertical photos taken from different heights. In this case, the photos should be set at different distances from the two eyes but in cases where differences of distances are small, enlarging or reducing one photo to the same scale as the other will remove most of the difficulty.

It may happen that one photo is tilted slightly with reference to the plane of the second photo.

Figures 7 & 8 show the effect of tilt on a photo being viewed stereoscopically.

A B C D and A′ B′ C′ D′ are two photos, principal points P and P′, exposed in the same plane.

All differences in parallax for points at different distances from the plane of the photos, are on lines parallel to the line joining the principal points.

If the right hand photo is tilted it will be distorted to the figure A″ B″ C″ D″.

In figure 7, in which there is fore-and-aft tilt, the effect of this tilt is to make points A and D appear further away than they should be, while points B, C, on the axis of tilt, are not affected. At the same time the distances of all the points from the principal point base is altered, A and D moving inwards and B and C moving outwards.

In figure 8 is shown the effect of lateral tilt. In this case A and C will appear closer and B and D will be further away; while A and B are moved outwards from the principal point base and C and D are moved inwards.

This movement at right angles to the principal point base gives what is called "*want of correspondence*". Theoretically with tilted photos in an ordinary stereoscope it is impossible to view all the photos stereoscopically at one time, but the accommodation in the eyes is so great that the effect is not always noticed unless compared to a grid or pointer.

It should be noted that small tilts do not cause appreciable "*want of correspondence*" for points along the principal point base.

21. *Effect of rotation of photographs in a stereoscope.*—If two photos are rotated so that the principal point bases are no longer coincident with each other and with the eye base, the effect will be as shown in figure 9. In the right hand photo A′ is the corresponding point to A, A″ is the image of the point, and A′ A″ is the parallax corresponding to the distance of A from the plane of the photographs. A′ A‴ and A″ A‴ are drawn parallel to and at right angles to the eye base.

Then it is obvious that the apparent distance of A will now correspond to the parallax A′ A‴, which is less than A′ A″, and A″ A‴ will be the amount of "*want of correspondence.*"

If photos are rotated till want of correspondence is eliminated along the eye base (see para 22), the principal point base will then coincide with it, as small tilts do not appreciably affect "*want of correspondence*" on this line.

22. *Patterns of grids.*—In a parallactic grid, lines at right

angles to the eye base will give a very definite effect of distances but will show up no want of correspondence.

Lines parallel to the eye base will show up "*want of correspondence*", but will give no effect of distance.

If a grid be composed of lines inclined at 45° to the eye base, it will give a fair effect of distance, and will also show up "*want of correspondence*".

Consider a point A in the left photo and A″ in the right photo, A′ A″ being *want of correspondence.* (See figure 10).

If A and A″ be fused, it is obvious that this point will appear nearer than line 1 and further than line 2. In practice the photos will normally give a stronger image than the grid. The effect will therefore be of the grid splitting: lines parallel to line 1 will appear under the photographic image and lines parallel to line 2 will appear above it.

When therefore the two lines of the grid coincide on the surface of the photographic image, *want of correspondence* has been eliminated.

SECTION III

METHODS OF AIR SURVEY

Their uses and limitations

23. *Methods dealing with individual photographs.*—The first time that air photos were used on a large scale for mapping was during the 1914-18 war on the western front. They were first used then for the revision of the old cadastral maps. These original photos were usually considerably tilted. There was however sufficient detail on the old map to enable individual photos to be "*placed*" exactly. These individual photos were either rectified and scaled or else detail was transferred to the map by the use of a camera lucida or by a system of squares.

This method has been used in France by Roussilhe since the war and has also been used in India. It is very laborious, and therefore expensive, dealing with individual photos. Theoretically the method is not suited to original surveys but should be very useful for revisions.

24. *Early methods dealing with strips of photographs.*—During the war, maps were made of enemy territory in Egypt and Mesopotamia in which there were few control points. These maps were made from strips of photos, but were not very accurate. The photos were joined up into strips by matching detail, a method which gives distortion whenever there is any relief in the ground or tilt on the camera. In Mesopotamia the country was flat and quite fair maps were produced very quickly. Strips of photos were brought to a common scale photographically and the map traced from a mosaic of these photos of strips.

This method was also used in the Irrawaddy Delta survey and gave good results. The country was flat and the flying good. In addition some allowance was made for tilt in joining the photos by matching detail.

In Wazīristān maps have been made by "strip" methods. No country could be more unsuited to air survey, and, even yet, there is no practicable method of producing a really accurate map in such country. In very mountainous country, the scale of photos is always varying. The method which has been used has been to rule a grid on the map and on the photo strip. Detail is then transferred square by square from the photos to the map. This method is now completely superseded by radial line methods.

Just after the war an attempt was made to use air survey for opening up unexplored country using vertical photography. This is far too expensive for the style of work and the method has never been actually used.

25. *Canadian "Oblique" methods.*—In Canada they have developed a particular system of air survey to suit a particular need. There are in the Dominion very large areas of forest on low lying and nearly level country, intersected with lakes and waterways. Maps are required of this country on about the ¼-inch scale so that the best way to open up the country may be decided. The only possible method of ground survey is by traverse along the waterways. This is expensive and slow.

The Canadian method of air survey is to use oblique photos. Knowing the position of two points in a photo on which the horizon appears, (the atmosphere is very clear and so this is possible), it is possible to rule a grid on the photos corresponding to the grid on the map.

The detail is then transferred square by square from the photo to the map.

When the aeroplane is carrying out photography, obliques are taken every 5 miles, from a height of 5,000 feet, one looking straight ahead, and two to either side, covering an arc of 90° on each side of the line of flight. The width of the strip which can be mapped from one flight of the aeroplane is thus about 10 to 20 miles.

A grid can be drawn on the first photograph from two points fixed by ground survey. The position of two or more points in the middle distance of this photo can be read off and these points used to rule a grid on the second photograph. A series of photographs can thus be joined together, little ground survey is required, and the method is therefore very quick and cheap.

It can only be used in a flat country with bold features and when the atmosphere is very clear. It is only useful for the production of maps on small scales (about ¼-inch).

26. *The radial line method* was then invented and this has revolutionised all "strip" methods.

This method was first used by Major Bagley in the U.S.A. about 1923. In order to simplify procedure he chose some point of detail near the principal point which was easy to recognise and drew rays from that. This is liable to introduce errors when tilt or relief is large.

This method has been elaborated by an American firm, Brock and Weymouth, whose method is probably the most accurate method, other than stereoplotters, now in use. They use a plate camera to do away with errors due to film and paper distortion. Having selected the minor control points, the heights of these points are found by ground survey. The photos are then examined in a stereoscope, and knowing the heights of the minor control points, the tilt of the photos can be found. The photos are then rectified photographically.

The method is then an exact one for joining up the strip, and for fixing the planimetry, and exact contours can be inserted under the stereoscope.

The firm use an elaborate measuring stereoscope of their own design.

The objections to this method are that it is slow and expensive. It is apparently a commercial success in the U.S.A. for large scale engineering plans where accuracy is required. It is not suited for the rapid production of topographical maps.

The general principle has since been taken up at home and Lieut. M. Hotine, R.E., has evolved the procedure known as the "Arundel" method. He shows that it is important to use the principal point itself, and this (as well as minor control points) should be transferred from photo to photo by *stereoscopic identification*, and not by measurement from neighbouring detail.

He also gives approximate rules for dealing with triangles of error which are due to tilt.

Full particulars can be found in "Simple Methods of Plotting from Air Photographs" by Lieut. Hotine, Professional Paper No. 3 of the Air Survey Committee.

This method was tried in Egypt by F.O. Lloyd. He found that with very accurate flying, which he himself was able to carry out, it was better to accept the principal point bases as correct in azimuth using secondary control points only to check scale.

This method can only be successful in flat country with very accurate flying. Only very specialised pilots can hope to give the accuracy required.

F.O. Lloyd has recently been employed by the Air Survey Company for their work in the Mālda district of Bengal. Here again they have used the "Egyptian" method.

This fixing of minor control is normally a purely graphical construction. For the Mālda work however two computed steps have been introduced. The control points are marked on the photos and also some point of detail near the principal point (this is the approximation Major Bagley accepted, but it may lead to errors). Rays are then drawn to minor control points from the point of detail near the principal point. The angles round this point are then read with a protractor. The chain of triangles of the minor control points of a strip is then computed and adjusted using rectangular co-ordinates.

The minor control points fixed by adjacent strips are then plotted on celluloid and adjusted graphically.

Theoretically this method cannot give greater accuracy than purely graphical methods, as graphical steps are used at the start and for adjustment. The advantages of the method are that computers do the majority of the work in place of expert draughtsmen. This makes for speed and economy.

27. *Stereoplotting machines.*—Another method of compiling a map from air photos is by the use of stereoplotting machines.

These machines were originally designed for use with ground photos. Under these conditions, the base between the 2 camera stations can be accurately determined and the photos can be exposed in the same or in parallel planes. The machine was then comparatively simple. For use with air photos, the machines must be capable of plotting from photos taken with an indeterminate amount of tilt and it must be possible to find the camera position from the photo itself. Machines with the necessary movements have been designed and made. Such machines are very cumbersome and expensive. Since the setting movements are all about axes which are horizontal and vertical, setting is a very lengthy operation. This makes the work slow and expensive. These machines have been developed chiefly on the continent of Europe and are capable of giving work of the highest precision. They will probably be used with oblique photos to reduce photographic charges and also to increase the area which can be plotted from one pair of photos.

A stereoplotting machine is now under construction at home in which all the setting movements are referred to the plane of one photo and an axis perpendicular to this. The second photo can then be set by eliminating *want of correspondence* at five points and when so set they will be in the same position relative to one another as at the instant of exposure. It should therefore be possible to set a pair of photos very rapidly. If this machine is successful, as it theoretically should be, it will enable an accurate air survey topo map to be made with the minimum of control, and will enable large scale maps to be made much more cheaply.

SECTION IV

FIELD WORK

FLYING FOR AIR SURVEY

28. *The problem confronting the flying personnel* is to cover the required area in the minimum flying time. Few pilots will agree as to the best methods to be used. The best book on the subject is "Flying for Air Survey Photography" by Captain F. Tymms, M.C., and Flight Lieut. Porri, R. A. F., published by the Air Ministry, Professional Paper No. 2 of the Air Survey Committee.

There are a few considerations which should be borne in mind in framing a scheme.

Flying for air survey is a very specialised job. It is dull compared to many other forms of flying, is often carried out in discomfort due to cold and is therefore sometimes unpopular.

The normal crew of an aeroplane on photography for survey is 2 men, pilot and observer. If the work is to be carried out well, these 2 men must both be very skilled, they must know each other's work intimately and must co-operate well.

In the R. A. F. it is laid down that the observer in a two seater machine is for defence only and can therefore do no photography. First class work cannot therefore be expected from a service two seater machine. Three seater machines are not yet available in India for photography.

Good flying makes for economy, not only in flying and photographic cost, but often in the cost of compilation as well, and contributes towards the accuracy of the map produced.

Should any gaps in photography occur, special flights have to be made to fill them and this may add considerably to the expense, owing to the difficulty of covering a definite gap in a subsequent flight.

The standard of accuracy which can be attained and should be aimed at is:—

Height of aeroplane maintained constant within 20 feet. This depends on the condition of the atmosphere and on how near its ceiling the aeroplane has to be flown.

Tilt in any direction not exceeding 2°.

Course sufficiently accurate in position and direction to avoid gaps and to ensure correct overlap between strips.

29. *Selection of aerodrome.*—An aeroplane can cover up to 50

miles from its base without any appreciable increase in cost and there is little increase if areas up to 100 miles away are photographed.

The photography can be carried out either by an aeroplane working from an aerodrome, or by a seaplane or flying boat working from water.

Should a base for air-craft have to be found before a scheme can be considered, the following points should be borne in mind:—

(a) An aerodrome should be 400 yards square and the surface should be such that a car can be driven over it at 30 miles per hour. The approaches should be clear. For seaplanes and flying boats a slightly larger area of water is required.

(b) The site must be accessible either by railway, a metalled road or a navigable waterway.

(c) Buildings (or at least water) are required for photographic work.

30. *Height of aeroplane.*—Before starting the photography it is necessary to decide the scale of the photos and the height from which photography is to be carried out.

To effect economy in photographic materials, and also partly in flying time, the scale of photography must be as small as possible.

The scale of the photos must be sufficiently large for the necessary detail to be identified. This will depend on the nature of the map being produced.

For topographical maps, it is considered in India and in America that the minimum scale of photos is about 1/20,000. The Air Survey Committee consider that about 1/50,000 should suffice if enlarged prints on the 1/20,000 scale were used.

In India, it has been found that small trenches are quite invisible on photos on about 1/15,000 scale even when these photos were enlarged or examined with a magnifying glass.

Plates and films used in aerial cameras have to be very "fast". This means that the emulsion must have a coarse grain.

There is therefore a limit to the amount an air photo can be enlarged before this "grain" becomes embarrassing. This limit is, at present, about 3 times.

The higher an aeroplane flies the more time is wasted climbing and descending. This adds to the cost. On the other hand the atmosphere is far less stable close to the ground and good even flying is, therefore, impossible.

In the plains, 10,000 feet above M. S. L. is a normal height for a machine doing photography.

Over mountainous country, machines often have to be flown as high as possible (i.e. 15,000 to 25,000 feet above M. S. L.). At these great heights, the cold is intense which makes it very uncomfortable for the crew: in addition the aeroplane has so little reserve climbing power that level flying is impossible.

Having decided on the height of the machine, the camera lens can be selected to give the required scale. For a given size of photo however there is a minimum focal length lens to cover the plate properly. This means that the photos will often be on a larger scale than would otherwise be required.

31. *Essentials regarding photography.*—Successful photography demands that successive strips be flown straight, exactly parallel, and with the correct overlap.

To do this, various instruments to find the strength and direction of the wind, and the height and speed of the aeroplane, are necessary.

When the machine is at its correct height and flying level, the camera must then be levelled and turned so that the short side of the film or plate is parallel to the line of the strip. In a cross wind the aeroplane will be pointing at an angle to the direction of the strip on the ground over which it is flying.

32. *Time for photography.*—Some consideration should be paid to the state of crops and foliage of trees when deciding the season at which photos should be taken.

Just after the rains, and before ploughing is carried out, it is hard in Northern India to distinguish between cultivated and fallow land.

When crops are high, it is almost impossible to distinguish field boundaries.

When trees are in full foliage they conceal a great deal of detail.

As regards the time of day when flying takes place, this is largely decided by flying conditions. It is essential however that the sun should be sufficiently high so that shadows do not obscure detail. Early or late flying in mountainous country is therefore useless.

33. *System of photography.*—The area to be photographed is divided up into sub-areas, usually rectangular, by key strips. All strips must begin and end on a key strip or on existing survey.

The general direction of the strips should be arranged so that the average height of the country in one strip is as nearly as possible constant. The time interval between exposures can be calculated as soon as the ground speed of the aeroplane has been found, and can be set on the camera which will then automatically take photos at this interval. This interval should be calculated to allow 60°/₀ overlap over the highest part of the strip. Or each photo can be exposed by hand, the necessary interval being found by means of an Aldis or similar sight.

If the exposure interval is kept constant during a run in which the height of the country varies considerably, the overlap over the lower parts of the country might considerably exceed 60°/₀. In such a case it would be advisable to alter the exposure interval during the course of the run.

34. *Aircraft for air survey* should permit of a good view vertically downwards and forwards. A pusher or twin-engined machine is therefore desirable. The machine should have a rapid climb, an endurance of about 5 hours, and should be steady at great heights.

It is an advantage if the machine is a three seater as then a pilot, a navigator and a photographer can be carried.

35. *Numbering photographs.*—Immediately after any photos have been taken, they should be developed and one copy of each printed. It is most convenient but not essential that this be done at the flying base.

Every photo must be given a distinguishing number which will always suffice to identify it. This number may take the form of a combination of letters and numbers e. g.

Letter or number for an area.
Number or letter for strips in an area.
Letters or numbers for photos in a strip.

With modern film cameras the photos are numbered automatically.

The prints should then be assembled to ensure that there are no gaps. It is a saving if this assembling is done by a detachment of the unit responsible for compiling the map who have to assemble the photos in any case to prepare their indices.

GROUND SURVEY

36. *General considerations.*—Whatever air survey is undertaken, some work on the ground will almost always be necessary. This work will include:—

(*a*) Fixing points on which the air survey will be founded.
(*b*) Fixing heights of some points.
(*c*) Ascertaining detail required for the map which is not obvious from the photos.

For ground work it is probably easiest to mount single photos on alternate pages in a note book, leaving a blank page opposite each photo for data to be entered in the field.

Only alternate photos in a strip need be mounted, the intermediate photos being carried in a pocket at the end of the book, so that they are ready for use with a pocket stereoscope.

37. *Details of work.*—As regards (*a*) fixing of control, this may be done by any normal survey method i. e. triangulation or traverse. When these points have been fixed, they have to be identified on the photos. There are two methods "*prepointing*" when marks are placed on the ground at fixed points before photography, and "*postpointing*" when the photos are taken out on the ground and objects appearing on the photos identified and fixed.

If *prepointing* is adopted, two visits to the ground will have to be paid, one to fix points, and one for the remainder of the ground work. This is usually uneconomical. *Prepointing* is normally only used under exceptional circumstances e.g. when traverse has to be completed in one field season, November to March and when aeroplanes are only available for photography in February and March.

When *prepointing* is adopted, useful marks are:—

Four trenches in the form of a cross each trench 10 feet long, 2½ feet wide and 1½ feet deep with the excavated earth piled up to the south and east.

Four white cloths each 6 feet square set in the form of a cross, with a blank area of about 5 feet square in the centre is another form of signal.

Lime or whitewashed marks have also been used but are liable to be washed away. If used, an annular mark 2 feet wide and 6 yards in diameter shows up well.

When *prepointing*, it is not always feasible or necessary to prepare marks on the ground which will appear on the photos; without such marks notes must be made of the situation and nature of the points fixed (some natural feature being chosen) so that they can subsequently be identified in the photos. This method was adopted in the Irrawaddy Delta Survey where the ground work could not be postponed and the expense of laying down marks was prohibitive. In this case owing to the absence of artificial detail, no ground work, other than pointing, was necessary.

When *postpointing* is used the expense of making marks is avoided.

As regards (*b*), heights may be fixed with sufficient accuracy by carrying round a battery of about 6 aneroid barometers.

As regards (*c*), extra detail required will include:—

- (*i*) All names which are to appear on the map.
- (*ii*) Classification of communications, roads, paths, railways etc. and insertion of milestones, fords and ferries.
- (*iii*) Width and depth of streams, and canals, canal milestones, whether perennial or not.
- (*iv*) Relative heights, cuttings, embankments, cliffs, karez, etc.
- (*v*) Churches, Temples, Mosques, P.O., T.O., R.H., D.B., C.G., etc.
- (*vi*) Classification of jungle.
- (*vii*) Description of marshes, bogs, areas liable to flood etc.
- (*viii*) Boundaries.
- (*ix*) Interpretation of detail obscured by trees or shadows.
- (*x*) High and low water line along tidal shores.
- (*xi*) Telegraph, Telephone and Power Lines.

38. *Use of air survey to help ground survey.*—Cases arise where it is required to make use of air survey as an aid to ground survey.

The best procedure in these cases is to provide the plane-tabler with prints of the air survey on tracing paper on the scale of his survey. When he has fixed sufficient controlling points, he can trace small portions of the air survey direct on to his plane-table.

SECTION V

OFFICE WORK

39. *Necessity for a map.*—It should always be remembered that the original compilation will almost certainly have to be reproduced. If the compilation produced is in a similar form to a plane-table section, it will have to be redrawn, thus wasting time and money. If possible, therefore, the original compilation should be fit for reproduction; and if it can be managed, the outline and contours should be drawn separately.

Although air photos give an exact picture of the ground from which any detail can be found, they are not as a rule so satisfactory as a map for the following reasons.

(*i*) A map is easy to understand and there is a table of symbols to which to refer.

(*ii*) It is cheaper to issue a map in large numbers.

(*iii*) Relief of the ground is not readily, if at all, visible on a vertical photo. In addition, the distortion due to this relief makes it impossible to produce an accurate mosaic of hilly country.

It is often however a help to an agency for whom the survey is being carried out, if they can be supplied with a mosaic on the same approximate scale as the map.

40. *Indexing and Filing photos.*—A great many photographs are used in any air survey. In order to save time at all stages of the work, it is essential that the photos are very carefully filed and indexed so that any particular photo required can be found at once.

The indexing and filing must be done before any compilation is commenced.

Photos should be filed according to their serial numbers or by strips, and each box of photos should be labelled with the numbers of the photos it contains.

An index map must then be made to show the positions of all photos. If an original map is being prepared, it will, at first, only be possible to show the relative positions of the photos, but as soon as possible an outline of the country and of the sheet limits should be added to this index.

41. *Some frame work of fixed points* is essential on to which the detail taken from the photos is to be fitted. In flat country 4

points per photo will suffice but in hilly country many more are required, the number varying with the distortion due to relief. These necessary points may all have been fixed by ground survey, (e.g. in cases of revision survey) in which case detail can be transferred direct from the photos. But in the majority of cases the number of points fixed by ground survey will be small for reasons of economy. In this case, more points will have to be fixed from the photos themselves using radial line methods.

Points fixed by radial line methods are known as "*minor control points*".

42. *Fixing Minor control.*—The first step in the fixing of minor control points is to mark these points, as well as the principal points on the photos.

The principal point may be pricked off from a specially prepared celluloid templet adjusted to the collimating points.

Two minor control points are selected on every photograph, one each side of the principal point, towards the edge of the photo, so that the lines joining these points to the principal point are approximately at right angles to the principal point base.

These three points are then transferred under a stereoscope to the preceding and succeeding photos and so on throughout the strip.

Two points are selected on any one photo which will control the scale of the plot of the strip. (See para 45 (*a*)).

The plot is made on a sheet of celluloid. This plot is made from prints of the photos. Owing to paper distortion, a certain amount of error is bound to be introduced. The scale of the prints is immaterial provided no distortion is introduced in an enlarging lantern. The same prints are, as a rule, used for this work and also for the interpretation of detail. The scale of the prints is chosen to suit this latter operation (see para 44).

The greatest care must be taken in making the plot as its accuracy depends to a great extent on the fineness of the drawing.

Take three successive photos A, B, C. (See figure 11).

Mark the principal points P_A, P_B, P_C on photos A, B, C and their positions on adjoining photographs $P'_A, P''_B, P'_B, P''_C, P'_C, P''_D$, as well as the minor control points 1, 2, 3 etc., and draw the rays from P_A, P_B, P_C through these minor control points.

All this work on the photos should be done in red ink.

Place photo A under the celluloid. Draw lines on the celluloid over P_A P''_B and the ray P_A 2. Mark the points P_A and 1 assuming that these two points are to control the scale of the plot.

Remove photo A and place photo B under the celluloid.

Orient it by placing P'_A P_B under the line on the celluloid and make the ray P_B 1 pass through the pt. 1 on the celluloid. Draw ray P_B 2 and thus the position of pt. 2 is fixed by intersection.

Draw ray P_B P''_C and rays P_B 3 and P_B 4.

Remove photo B and place photo C under the celluloid.

Orient it by the ray $P'_B P_C$ and place it so that the rays P_C 1, P_C 2 go through the positions of these points.

If there has been tilt on the photos, both these rays will not pass through the plotted points. The method of dealing with the triangle of error due to tilt is given in Prof. Paper No. 4 of the Air Survey Committee, page 11.

Draw rays P_C 3 and P_C 4 and thus fix the positions of minor control points 3 and 4.

Care must be taken to ensure that some of the minor control points are common to two adjacent strips so that lateral adjustments can be carried out.

All points fixed by ground survey must also be marked on the photos and fixed on the minor control plot by intersection.

Any minor control plot on which two or more points fixed by ground survey appear, can then be brought to standard terms and these terms can be carried to adjacent strips by using common minor control points.

A check is provided when more than 2 fixed ground control points appear on a strip and in the common minor control points which have been fixed independently on two adjacent strips.

43. *Interpretation of hill features.*—Before the detail for the map is coloured up on the photos, the form lines or contours should be coloured up. This is done with a coloured pencil under a stereoscope using a parallactic grid. The system on which this is done is similar to that used in plane-tabling i.e. no attempt is made to survey one contour in its entirety but the ruling points where the contours cut the spurs and streams are first marked, the main contours are then completed and finally intermediate contours are inserted to show underfeatures and changes of slope.

When the photos are tilted "*want of correspondence*" is liable to give trouble. In this case the cutting points of the contours should be marked along lines joining every two points whose height is known, the photos being re-adjusted for every pair of heights. The normal procedure is then followed, but only a small portion of contouring should be attempted without re-adjusting the photos.

44. *Interpretation of detail.*—Detail which is to appear on the map should first be marked up on the photos. This is best done with coloured pencils, before the ground survey is carried out so that doubtful detail can be interpreted on the ground. The stereoscope should be used when marking up this detail.

If the map is on a larger scale than the original photos it is convenient to use enlargements of the photos to the approximate scale of the map. Otherwise contact prints can be used.

Detail which will not be required on the final map, should not be coloured up on the photographs.

45. *Methods of compilation.*—When sufficient points have been fixed and the detail which is to appear on the map has been coloured up, there are several possible ways of proceeding, three of which are given here:—

(*a*) The detail may be transferred to the celluloid strips on which the minor control plot has been made. This is advisable when the scale of the photos is not constant, either due to relief in the ground or to strips being photographed from different heights. When this method is adopted, the scale of the celluloid plot should be approximately the same as of those photos on which the detail is most dense, or in the case of high mountains should be about the mean scale.

The plot can then be reduced to a common scale either photographically, by pantagraph, or by a system of squares.

In the first case a mosaic can be made from the photos of the strips and the fair sheet drawn on a blue print of the mosaic. In the other two cases the detail can be transferred direct to the fair sheet and inked up fair.

The celluloid plots should be completed as plane-table sections.

In some cases, e.g. when relief is great, and when there are large tilts and few control points, the plots may be so distorted that it would be impossible to make a satisfactory mosaic for fair drawing. In this case, a compilation sheet will have to be made by transferring detail square by square from the plots and making necessary adjustments.

(*b*) A controlled mosaic may be made from rectified or unrectified photos.

For this all the fixed points, i.e. ground survey and minor control points should be plotted on one sheet of drawing paper, or bristol board, for each map sheet.

Scaled or rectified prints are then cut, adjusted and pasted down on the board in their correct positions relative to the plotted points. It has been found that for settlement maps of flat country on the 24-inch scale, rectified prints are not necessary, provided the flying is good; and all necessary adjustment can be made in pasting down the scaled prints which may be cut into sections where necessary. A fair trace can then be made on celluloid from the mosaic and vandyked for reproduction.

(*c*) All the control points can be plotted, or a blue pull of the map can be printed on a sheet of celluloid or drawing paper for the preparation of the fair sheet. The detail is then transferred photo by photo to the fair sheet.

This transferring may be done in many ways.

(*i*) By projecting the image of the photo into its correct position using an epidiascope.

(*ii*) By the use of a camera lucida.

(*iii*) A grid may be ruled on the map and on the photos and the detail transferred square by square.

(*iv*) The detail may be traced from rectified prints.

(*v*) The detail may be transferred from unrectified prints, necessary adjustments being made while doing the transferring.

(*iv*) and (*v*) are most easily carried out when the fair sheet is being made on celluloid.

SECTION VI

INSTRUMENTS

46. *Cameras.*—The instruments used in air survey are continually being improved. In this section it is only possible to give a general outline of them.

Aerial Cameras

These cameras take either plates or films.

Considerations affecting the use of plates are :—

(*i*) They are heavy and bulky.

(*ii*) Only about 18 will fit in one magazine and time is taken changing magazines.

(*iii*) They are virtually true planes and better adapted to exact measurements than films.

(*iv*) Plates are usually arranged to drop into position. There is not usually much error introduced by this but when precise work is required and it is necessary that the plate be exactly in the focal plane, some means of pressing the plate against stops must be introduced. This of course complicates the camera.

(*v*) They do not distort on development.

(*vi*) They are liable to damage with rough use.

Considerations affecting the use of films are :—

(*i*) They are light and compact.

(*ii*) Up to 100 exposures can be taken on one film.

(*iii*) It is hard to ensure that a film remains in the focal plane for all exposures. It is usual to have a sheet of glass in the focal plane and to press the film on to this glass.

(*iv*) They are liable to slight distortion on development.

Shutters are either "between lens" or "focal plane". The latter cause distortion but difficulty is experienced in making the former admit enough light in the short exposures necessary.

A lens will only cover a cone with an apex angle of about 60°. If it is required to photograph a larger area, a multi-lens camera is necessary.

Multi-lens cameras are really two or more separate cameras rigidly connected and exposed simultaneously. This is now done electrically.

Some cameras now in use are:—

(*a*) *L.B.*—Used in the R.A.F.; now obsolescent but common in India: uses plates 5″ × 3⅞″, 18 in a magazine: lens 6″, 8¼″ or 10″. Focal plane shutter.

War time camera. Normally not fitted with collimation marks: these should be added.

(*b*) *F. 8 or Eagle.*—New film camera designed by Air Survey Committee. Photos 7″ × 7″ with strip recording serial number, levels, height, time. The number is the most useful item.

Films are in rolls of 25, 50 or 100 exposures. Film is pressed on to the glass in the focal plane with pressure pad. Exposures are made automatically by electricity. Special developing apparatus necessary.

Camera took some years to produce, and has now been in existence for about 2 years. There are still minor defects. Has focal plane shutter. Between lens shutter under design. Lens 7″, 10″ and upwards.

(*c*) *Fairchild.*—Film camera made in U.S.A. and used there and in Canada. Has been in use for many years and takes excellent photos. A vacuum is used to keep film in contact with glass plate in focal plane.

Between lens shutter. Size of photo 9½″ × 7″. Lens 8″, 10″, 12″, 20″.

New models show film records similar to the F. 8 but in a very much smaller space.

(*d*) *Air Survey Committee Tri-lens.*—This camera is designed so that one lens points back to known country thus fixing the camera position, a second lens points vertically down, while the third lens points forwards to fix control ahead.

To use 6″ lens and plates for work of the highest precision.

(*e*) *American Tri-lens.*—This camera is designed so that the central lens points vertically downwards and one lens on each side is inclined at 35°. The three lenses then cover a strip subtending 120°, or in other words the width of the strip photographed is about three times the height of the aeroplane.

The Americans have recently been experimenting by adding a fourth lens pointing back and a fifth lens pointing forward.

Three lenses are used only to get a wider field of view. The three photos taken all join up. The camera uses films. The two inclined photos are rectified in a special rectifying camera, on to the plane of the central photo. A composite vertical photo is thus produced and used like any other vertical.

Lens 6½″ in the centre, 7½″ the two side lenses.

Between lens shutters.

47. *Tilt Finders.*—An aeroplane travels very fast, 80 to 120 miles per hour, and therefore when its course is at all curved, any spirit level on the machine is considerably affected. It is therefore impossible to rely on levels to give the tilt of the camera.

The Air Survey Committee experimented with a gyroscope to control a spot of light which was photographed on the plate when an exposure was made. From the position of this spot on the plate, the tilt at the moment of exposure would be known. This was not a success as it was impossible to stop the gyroscope "*hunting*".

A German firm have recently tried photographing beams of light from the ground of which the angles of elevation are known. This would be too elaborate for general use.

Lieut.-Colonel M.N. MacLeod, D.S.O., R.E., has designed a tilt finder. In this instrument the photo and a map of the control points are viewed together in perspective and the photo is tilted till it appears to coincide with the map. A model of this instrument has been made by Barr and Stroud.

It is doubtful whether the tilt of the camera will ever be prevented. The easiest method of determining the tilt will probably be by eliminating *want of correspondence* in an instrument such as that described in para 27 last sub-para.

48. *Camera Lucida.*—By the use of this simple instrument an image of a photo can be seen over a map sheet. The detail can then be transferred from the photo to the map. The photo can be tilted, and its scale altered by altering its distance from the instrument.

49. *Enlarging and rectifying Lanterns.*—Any commercial enlarging lantern should be suitable for air survey work. It should be tested to ensure that the photo carrier and copy board are truly parallel. Most modern lanterns have automatic focussing arrangements.

A condenser of the necessary size to cover a 7″ × 7″ plate would be very bulky and heavy, therefore a source of light, with a parabolic reflector, behind an opal glass is generally employed. Provided tilts are small an ordinary enlarging lantern can be adopted to give rectified prints by fitting a universal movement to the copy-board. A suitable autofocus lantern is made by Williamson and Co.

If it is desired to rectify large tilts a lantern must have the following movements:—

(*a*) The copy-board and plate-holder must be capable of rotation about the normal optical axis of the lens.

(*b*) The plate-holder, lens and copy-board must be capable of rotation about parallel axes at right angles to the normal optical axis of the lens.

(*c*) The distances apart of the plate holder, lens and copy board must be variable.

A German firm have designed a lantern which automatically adjusts itself for tilt i.e. if the copy-board is tilted, the plate-holder and lens are set accordingly. Automatic focussing is not included in this lantern.

An epidiascope is a form of lantern, but the image on an opaque surface is projected on to the screen, and a transparent plate is not necessary. Variations of scale are made in the same way as with an ordinary enlarging lantern and small tilts can be overcome by tilting the copy-board.

50. *Stereoscopes.*—Normally a person's eyes are 6 to 7 cm. apart (interocular distance). When the parallax of an object is equal to the interocular distance the rays from the two eyes will be parallel and the object will appear at infinite distance. This is normally the limit of parallax which can be viewed directly. Photos which it is required to examine stereoscopically may be as much as 20 cm. wide. If an object in the centre of a 20 cm. photo is to be viewed stereoscopically the parallax must be 10 cm. to avoid one photo obscuring the other. Some optical device is therefore essential to divert parallel rays from the eyes 6 to 7 cm. apart on to two images 10 cm. apart.

There are several methods of doing this. These are:—

(*a*) A prism opposite one or both eyes. This is unsound unless the photos are placed normal to ray from the prism to the photo. When this is done the photos are not easy to illuminate evenly, or to draw on and complications arise in introducing parallactic grids.

(*b*) A system of 2 parallel mirrors opposite each eye set at 45° to the line of sight. One disadvantage of this is that the distance from the eye to the photo is increased but this is counter-balanced by the fact that a larger area of photo can be viewed easily at one time. This method is employed in the Barr and Stroud stereoscope. Fitting of parallactic grids is easy and the photos are horizontal to be drawn on.

(*c*) A system of lenses and prisms similar to an ordinary pair of prism binocular field glasses. This type may be developed in the future as the parallactic grid can then be placed in the optical system leaving the photos free for drawing; any desired degree of magnification can be obtained.

A convex lens opposite each eye, of focal length equal to the distance from the eye to the photo, is of assistance in viewing stereoscopic photos. This may take the form of spectacles.

51. *Stereoplotting machines.*—When two photos are viewed stereoscopically, an apparently solid object is seen. If two marks are placed in the field of the two eyes, the fused image of this mark will be at a definite position relative to the eye base.

If the two marks be separated, the fused mark will appear further from the eye base. In addition the fused mark can be made to move to right and left or up and down by moving the two marks together.

The two marks can be joined up to a pencil on a drawing table so that the pencil traces the movements of the pointer, which may be made to follow detail in the stereoscopic image.

When the stereo photos are exposed in the same plane, such a plotter is quite a simple instrument.

Lieut. Thompson, R. E., made an instrument on these lines in 1908 and a more elaborate machine was designed by Von Orel and made by Zeiss about 1914.

When the plot has to be made from tilted photos, the theory of the machine is still comparatively simple, but many complications are introduced in the optical system. The photos are mounted in photogoniometers and the line of vision from the two eyes is taken to the 2 photogoniometers.

The first universal plotter i. e. one which would plot from photos with any tilt, was made by Hugershoff in Dresden. This was soon followed by a machine made by Zeiss. These machines have extremely intricate optical systems, and are very elaborate, complicated and bulky. No one but an expert can adjust them. When in adjustment they will give very accurate work.

Wild, a Swiss, has recently constructed his "*autograph*" which is much smaller and neater than the first machines and can turn out equally good work. The optical system is still very complicated and it requires an expert to work it.

Hugershoff has lately brought out a smaller machine on very similar lines to the Wild. In this machine a device is introduced by which the lines of vision from the eyes to the two photos can be interchanged.

When the tilt is known, a pair of photos can be set in any machine comparatively quickly (one hour) but when the photos have to be adjusted to four fixed points, setting the photos is a very lengthy process and may take several hours.

So far no simple and effective method of avoiding or finding the tilt has been discovered. The simplest method is to find relative tilt by eliminating *want of correspondence* under a stereoscope.

Fourcade, a South African, has designed a stereogoniometer on this principle *vide* para 27 last sub-para. The setting of this is independent of ground control, and is likely to prove very successful. In addition to finding the relative tilt, an automatic plotting gear can be incorporated. A machine of this design is now under construction at home.

Most stereoplotting machines embody the principle of the Camera Plastica. The two photos under examination are placed in two lanterns and arranged in similar mutual positions to those occupied by the original plates at the moments of exposure. Two images are cast on to the copy-board. The two images will only fuse into one image when the copy-board is set with relation to the two lanterns in the same terms as the two lanterns themselves are set. A map can then be traced off on the copy-board.

An Italian firm Nistri have made a successful machine on these lines. A similar machine has been made by Cooke, Troughton and Simms for the War Office and is now in Southampton. This instrument has not all the movements which are required and so its use is limited.

SECTION VII

WORK DONE IN INDIA DURING THE LAST FIVE YEARS.

52. *Irrawaddy Delta.*—3 inch Forest Survey 1,500 square miles.

Photography by the Air Survey Company.

Control and compilation by No. 18 Party, Survey of India.

Country flat with thick jungle. Very difficult for ground survey and very suitable for air survey.

Photos were pinned down in strips and the strips reduced to scale photographically. Work was successful, but somewhat expensive as this had to bear the cost of two aeroplanes.

53. *Work in Wazīristān* and other tribal territory, 1,500 square miles.

Photography by R. A. F.

Control: very scanty, fixed under active service conditions.

Compilation by No. 18 Party, Survey of India.

Country very mountainous and very unsuited for air survey, even under otherwise favourable conditions. In this case the ground cannot be visited and, for various reasons, the photography was not very good.

Maps have been produced which are undoubtedly inaccurate, but these maps do give some representation of the ground, and although this may be displaced from its true geographical position, the maps will be of the greatest assistance to civil, military and air force officers who are working in the country.

The factors which caused the bad photography are:—

(*i*) Obsolete cameras.
(*ii*) High winds.
(*iii*) Changing personnel.
(*iv*) Lack of maps on which a programme could be laid out.
(*v*) Lack of specialist survey pilots in the R. A. F.

54. *Peshāwar District.*—Experimental survey on the 24-inch scale of Lahor village.

Control by Settlement Survey Detachment, Survey of India.

Photography by R. A. F.

Compilation by No. 18 Party, Survey of India.

The country is nearly flat and suitable for air survey.

Individual photographs were rectified on to fixed points.

Perfect rectification was impossible as a focal plane shutter was used.

Resultant map proved quite accurate enough for settlement work.

The work was uneconomical as an unnecessary amount of ground survey had to be undertaken.

Photos were taken at a bad time of year when maize crops were high and obscured field boundaries; and in other cases it was impossible to distinguish waste land from unploughed fields.

55. *Attock District.*—Experimental survey on 16-inch scale of four villages.

Control by Settlement Survey Detachment, Survey of India.

Photography by R. A. F.

Compilation by No. 18 Party, Survey of India.

The area contains low hills but not high enough to seriously affect air survey.

Individual photos were rectified on to four fixed points each. Focal plane shutter was used and therefore perfect rectification was impossible. It was also found that the fixed points were not sufficiently accurate for rectification.

Prepointing was tried and failed as white marks were washed away before photography.

The resultant maps were sufficiently accurate.

The survey was uneconomical as unnecessary ground survey was carried out.

The advantage of air survey was that villagers were not disturbed.

56. *Map of Riverain area* near Dera Ismail Khān, 4-inch scale, 100 square miles.

Photography by R. A. F.

Control. Old fixed points along river.

Compilation by No. 18 Party, Survey of India.

The country is flat and suitable, but haze over the river made the photographs indistinct.

The photographs were brought to a common scale and a mosaic was made. The map was traced from this mosaic.

The map was only required to discover movements of river and was quite accurate enough for that.

57. *Multān guide map.*—4-inch scale, 110 square miles.

Photos by R. A. F.

Control. Taken from the old 6-inch map.

Compilation by No. 18 Party, Survey of India.

The country is flat and suitable for air survey.

Postpointing was carried out.

It was intended to join up strips by the Arundel method but overlap was often less than 50 %. All strips possible were put down by this method and the remaining strips were joined by principal point bases, reduced photographically and fitted in.

The resulting map is as accurate as ground survey on the same scale.

58. *Bengal.*—Construction of rectified mosaic on the 24-inch scale of a village, Mauza Sadhanpur.

Photos by the Air Survey Company.

Control by traverse.

Compilation by No. 18 Party, Survey of India.

The original intention was to construct a mosaic from rectified prints.

The difficulties of the focal plane shutter and inaccuracies of the traverse data were again experienced. Direct enlargements were therefore made of every photo. Difficulty was experienced in fitting these photos into a mosaic but it was possible to make the necessary adjustment by tracing the detail direct off every photo on to a fair trace.

The fair trace was found by the Director Land Records, Bengal, to be sufficiently accurate.

The success of this work decided the Bengal Government to undertake a large programme of air survey.

59. *Chittagong Forest Surveys.*—On the 4-inch scale, 1,380 square miles.

Photography by the Air Survey Company.

Control pricked off from old maps.

Compilation by No. 18 Party, Survey of India.

The area consisted of low hills covered with jungle.

Owing to distortion of the old maps and misidentification of some of the points the control was not good. In addition, in some places, there were no fixed points.

The production of an accurate map would therefore have been difficult in any case.

Had it been possible to use the Arundel method a very satisfactory map might have been produced.

The photography was however carried out before the method of compilation had been decided. In order to cut down photographic costs, the Air Survey Company had reduced the forward overlap to less than 50 $^{\circ}/_{\circ}$. The Arundel method was therefore impossible.

Owing to the dense jungle it was impossible to be sure of the lines of drainage unless a stereoscope were used and, even then, the location of the low flat saddles in valleys between parallel ridges was uncertain. As the overlap was less than 50$^{\circ}/_{\circ}$, the use of the stereoscope was not always possible.

The resultant maps cannot hope to be very accurate but they will probably serve their purpose and enable the forest officers to decide how to work the forests.

60. *Northern Command Survey Exercise 1927.*—

Photography by R.A.F.

Control by "A" Company under active service conditions.

Compilation by No. 18 Party.

The area was very hilly.

Maps on the 1-inch and 3-inch scales were produced in the time required.

Points fixed were marked on oblique photographs and so recognised by the compilers.

The American radial line method was used as this is quicker than the Arundel method although it is not so accurate.

Reduction of strips to the scale of the map was done by pantagraph: two men being employed on one pantagraph.

The maps reproduced would have been of immense value to any force operating. Further training is required, particularly to speed up the work using more rigorous methods and to depict the hill features better.

61. *Mālda District of Bengal.*—Settlement Surveys.

Photography by Air Survey Company.

Control by theodolite traverse by the Bengal Survey Department.

Compilation by Air Survey Company.

This work has not been a success.

It was the first attempt to carry out a 16-inch survey of a large area for revenue purposes, and there were many difficulties in meeting the requirements of the Local Government.

It would have been far better had it been possible to spread the work over two seasons, allowing a very small programme the first season, so that methods might be tried out, and the personnel trained before tackling the major part of the work.

The flying was carried out too late in the season, and photography was not therefore of the best.

The personnel employed were not wholly familiar with the radial line method of compilation employed, and the maps prepared failed to reach the standard that had been contracted for.

The maps were rejected, and ground survey is being adopted instead.

A portion of the area has however been set aside for a further experiment in air survey, and instead of compiling by radial line methods, individual photographs are to be rectified on to four traversed points in each photo.

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G

O.

PARA

P.

R.

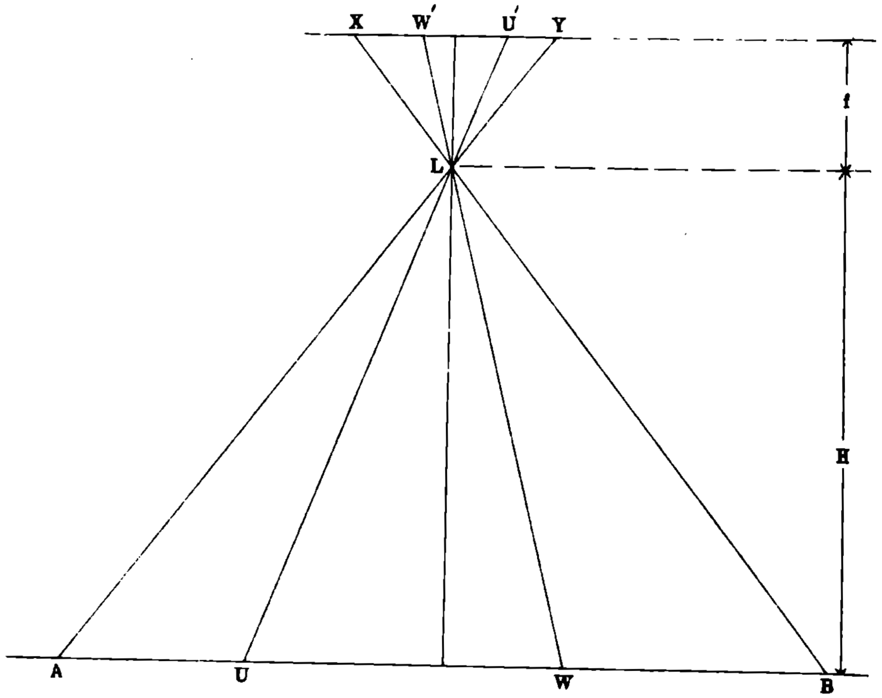
R.—(*continued*).

S.

T.

W.

PLATE I



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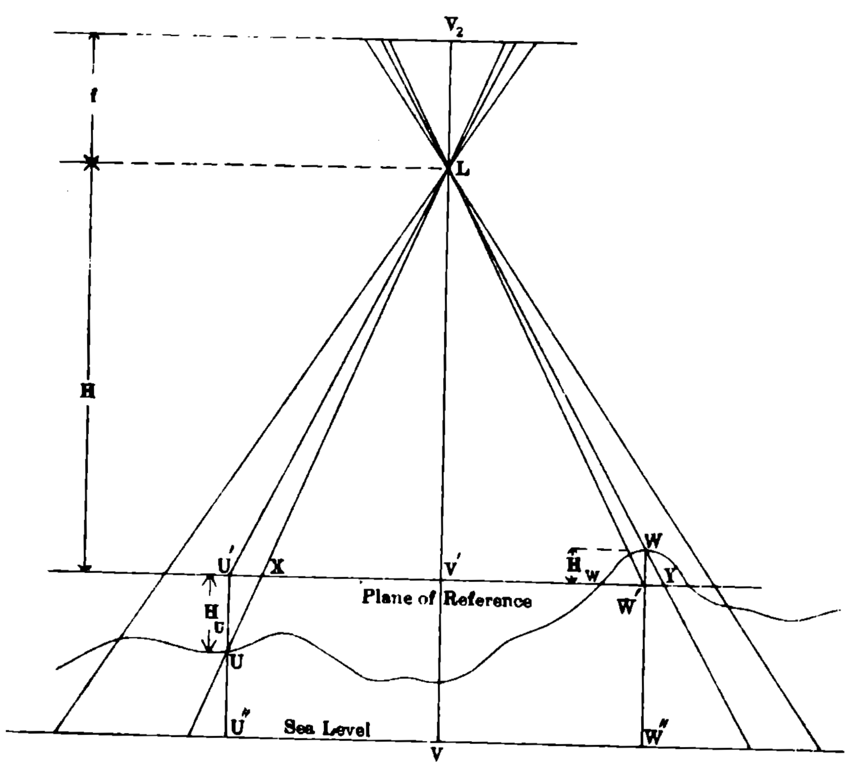
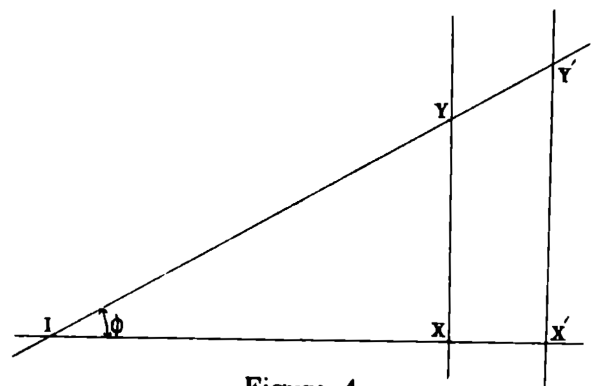


Figure 2



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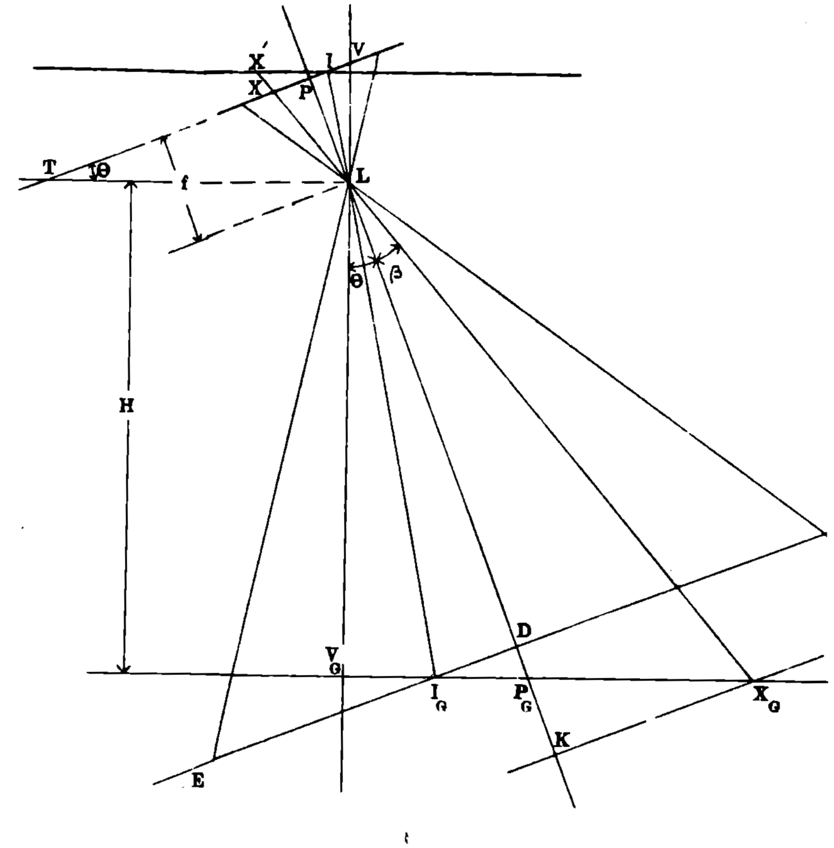

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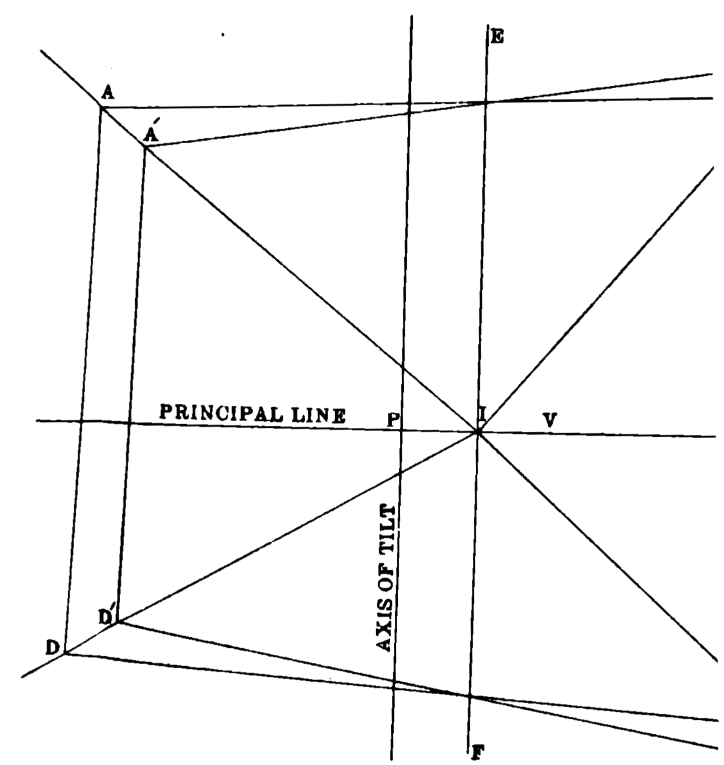
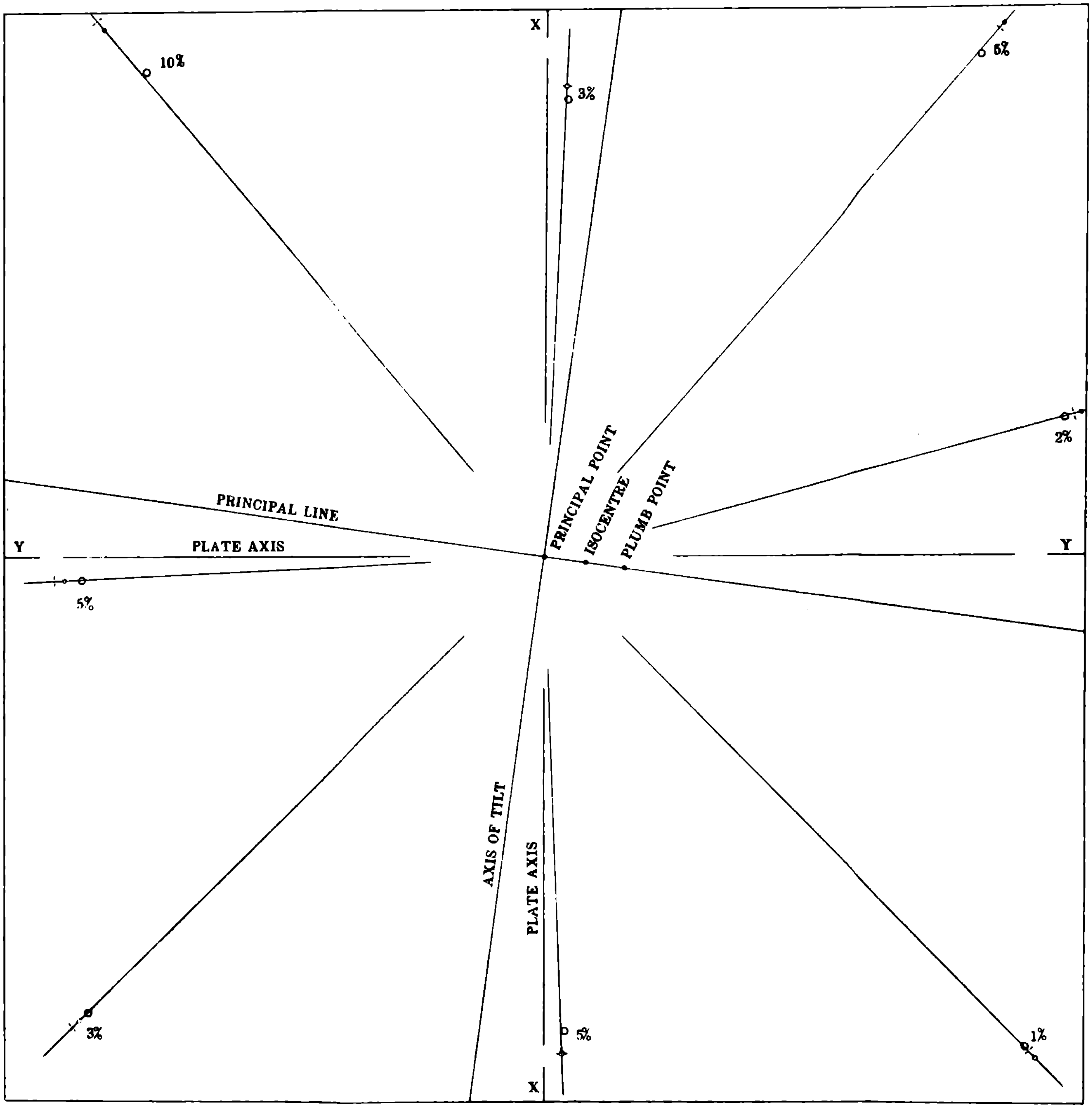


Figure 5

PLATE II

To show the distortion on a 7 inch X 7 inch photograph taken with a tilt of 3° using a 10 inch lens.



X.X. Y.Y. are collimating points.

The numbers entered against the various points are the heights of these points compared to the height above the ground from which the photo was taken.

——•—— represents the image of a point on the photo and the ray through it from the principal point.

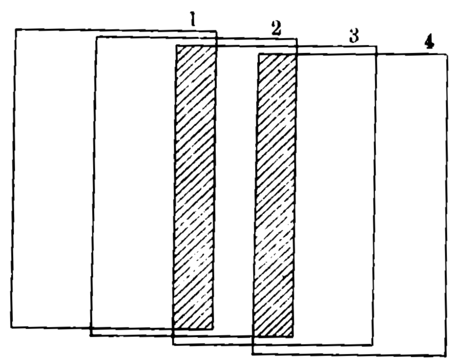
○ represents the undistorted position of a point.

¦ represents the position of a point allowing for distortion due to relief but not for distortion due to tilt.

The distance ○--¦ represents the amount of distortion due to relief.

The distance ¦—• represents the amount of distortion due to tilt.

PLATE III



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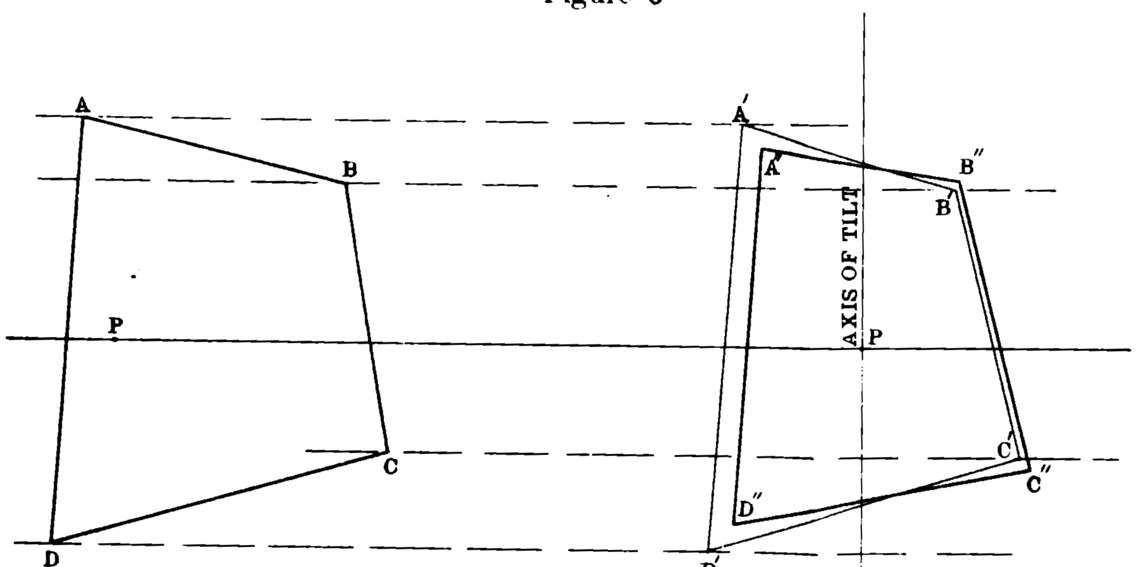

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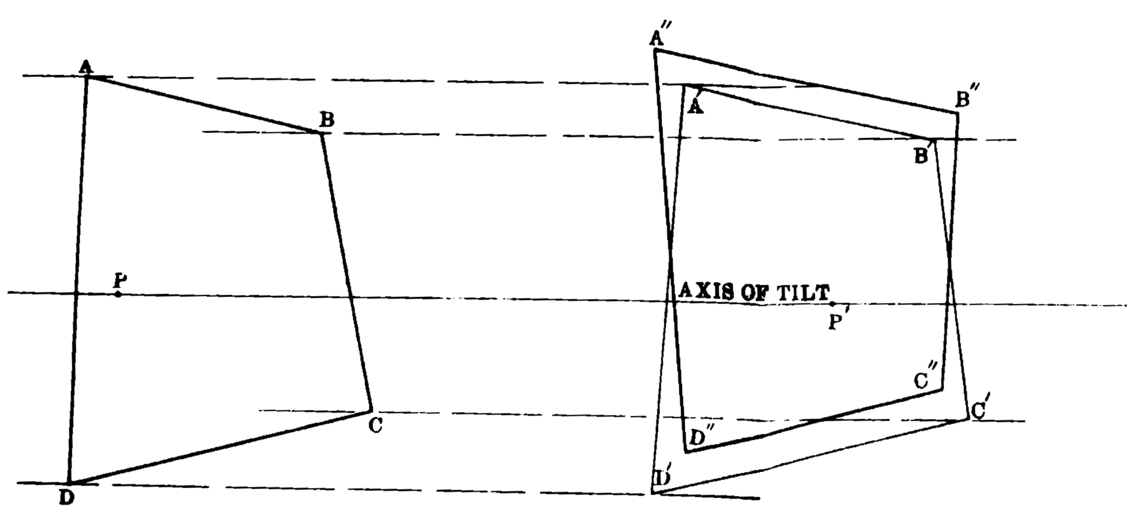
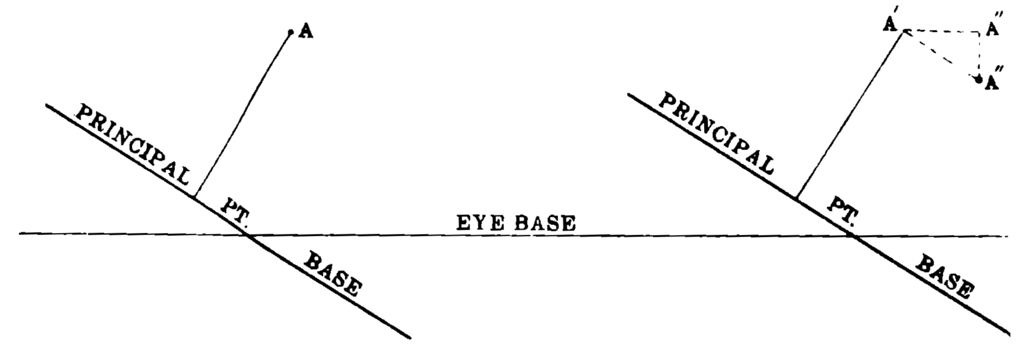


Figure 8



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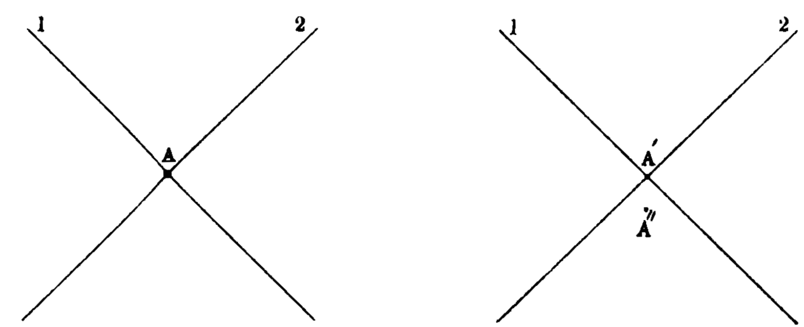

Figure 10

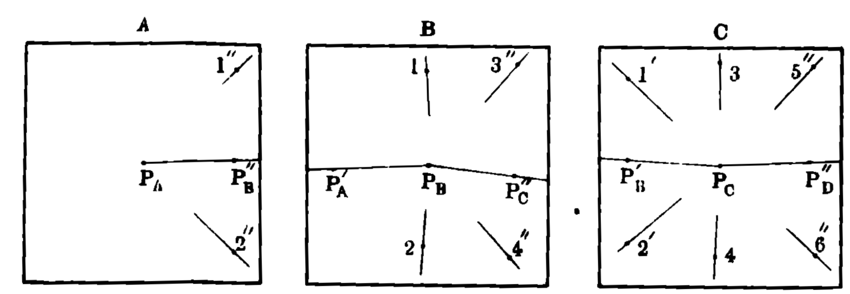

Figure 11