AERIAL PHOTOGRAPHY

THESIS FOR THE DEGREE OF B. S.

ROBERT OWEN SCHAEFFER

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AERIAL PHOTOGRAPHY

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by

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Robert O. Schaeffer
Class 1938

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Aerial Photography

INTRODUCTION

The development of the airplane was followed by the development of aerial photography. The great rapidity with which large areas can be photographed make the method of photography of great value for commercial and military purposes. Photographic maps can be made in a small fraction of the time required by any other method of mapping, and the airplane can reach terrain that for some reason may be inaccessible to the surveyor or sketcher. Photographs are timely, and portray many details of the terrain that are lacking on the most complete topographical map. Thus aerial photographic maps are of great value to the surveyor in both the commercial and military.

I will try to describe in the following pages the progress of this science and the type of equipment and methods used in making maps from aerial photographs. One should not get the impression from this thesis that the following described methods are the best or most used, as the material used here was gained from observations made at Abrams Aerial Survey Labratories in Lansing, Michigan. It also must be remembered that this science is now progressing at such a rapid rate that what may be a good method today will be obsolete tomorrow

HISTORY

The science of aerial photography began in 1861, when two men made an oblique photograph of Boston from a captive balloon at an altitude of 1200 feet. Although much information was gained from this and other later flights, aerial photography was slow in developing until the development of the airplane. By 1911 the airplane had been developed to the point where passengers and equipment could be carried, thus photographing from the airplane became possible.

The airplanes of this time were light in construction and the pilot and passenger sat in open cockpits. It is known that the motion of the airplane in the air causes wind of realitively high velocity. This wind made aerial photography very difficult with this early type of equipment. Clear pictures were hard to obtain because of this wind and the motion of the plane. To overcome this, cameras were designed especially for aerial use. Plates have been replaced by roll film which is much lighter. Multi lens cameras are now used so as to cover a large area in one exposure.

Though slow in development in the commercial field, aerial photography has been used to quite some extent in the army. During the World War aerial photographs were taken of enemy position and used to a large extent by the artilleries in preparation of firing data. They have developed it now so that an airplane can take a picture of the enemy positions, develop it in the air, and drop the print to the supporting artillery. This is all done in a short space of time.

CAMERA

There are various types of cameras on the market for use in aerial photographic work. These cameras can be divided into three classes:

1. The single lens type, with focal length varying from 6 to 28 inches, with between the lens shutter or focal plane shutter. Uses film.

2. The Brock Camera, which is a special type that uses plates instead of film. This type is not very common.

3. The air service camera having one or multiple lenses in a group. The focal length varies from 6½ to 7½ inches. This type uses film.

A good example of the single lens camera is the Fairchild, Type 4, general purpose, which is used by Abrams Aerial Survey Corporation of Lansing. This is a fixed focused type using an 8¼ inch lens. These lenses are especially selected so as to get the greatest amount of accuracy. The focal length of the camera is fixed but can be changed by changing the cone and the lens. The distance from the lens to the film is fixed and focused at infinity which will allow for the small variations in altitude of the airplane while pictures are being taken. This type uses roll film 9½ inches wide and 75 feet in length with 110 exposures. Each exposure is 7 by 9 inches. Some of the principal advantages of this type of camera are: the large image area, shorter focal length, greater amount of film. The large image area gives a better and greater coverage, the short focal length allows the plane to fly closer to the ground, and the greater amount of film makes duplication of prints possible.

The camera constructed of a light metal, such as Dow Metal, is mounted in gimbals. (Some have a fixed mount thus giving tilt to many of the exposures). Each camera has a view finder so as to beable to check exposure. The photographer levels his camera, so as to get a vertical shot and checks his view finder beforeeach exposure. Most American makes of cameras are electrically driven while some foreign makes are driven by a wind mill on the outside of the airplane. The mechanism driving the camera sometimes causes static. Static isvery undesirable as it causes black dots on the film.

Multi-lens cameras such as those used by the air service have from one to ten lenses in a group. In this typ e of camera the exposure is usually made with the axis of the central lens vertical but the other inclined at a large angle, the latter all taking oblique pictures. (Fig. 1). These oblique photographs called wing pictures all have to be rectified so as to give the equivalent of a vertical photograph. The method of doing this will be described later. The advantage of this type of camera is the great amount of area photographed in a small amount of time. Its main disadvantage is in rectifying the wing picture which leaves a large chance of error in the photograph.

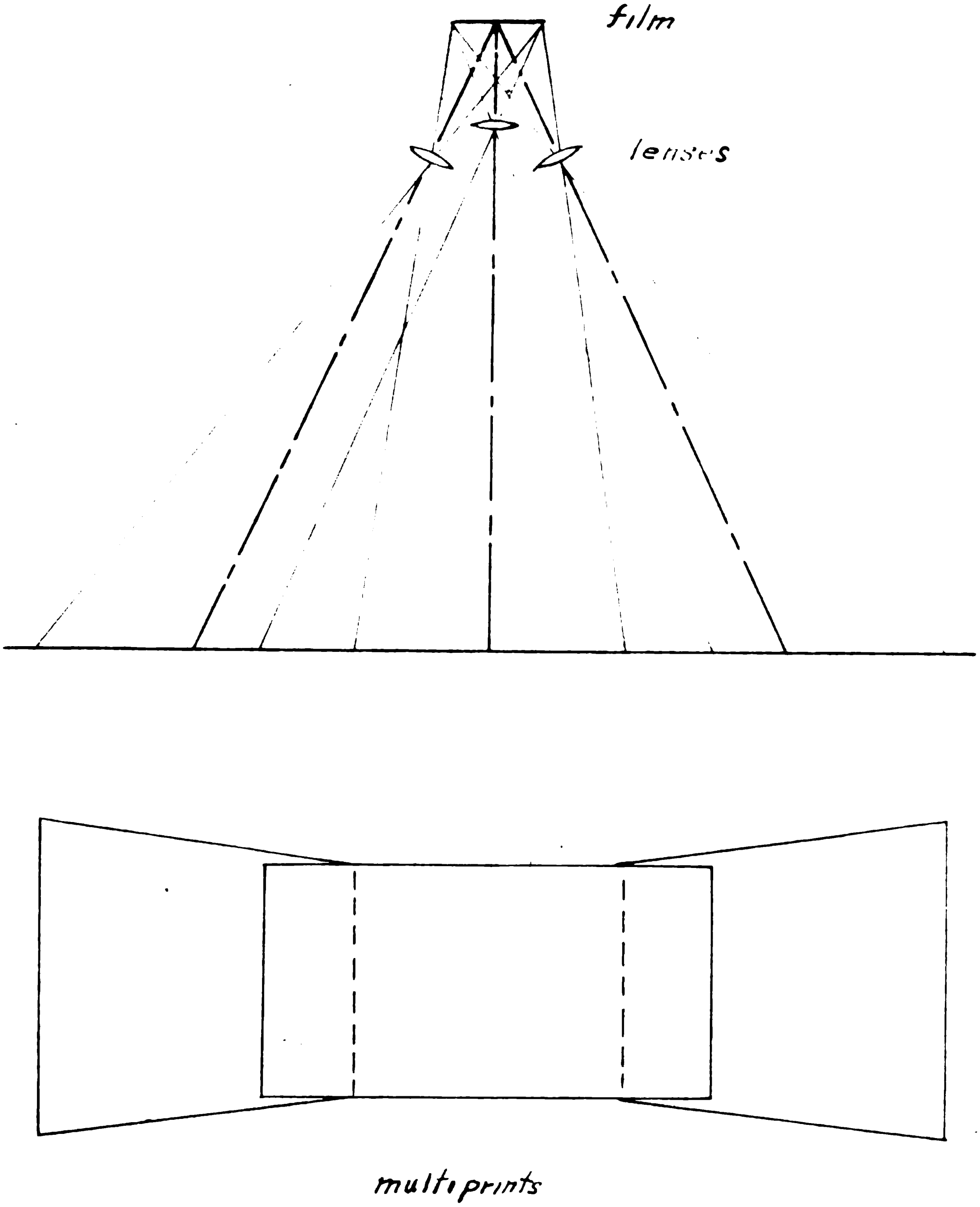

Fig. 1

MULTI-LENS
(3 Lenses)

R.O.S.

PLANE

The type of airplane used in photography should be designed for the work. It should have means of rapid climbing so that time will not be lost in gaining the required altitude (22,000 feet). There should be means of good visibility for both the pilot and photographer. The pilot requires visibility not only ahead but also below so as to maintain his course. The photographer needs the visibility to enable him to do a good job of photographing. The ship must also be as nearly stable as possible so as to eliminate distortion due to tilt and maintain a constant altitude and speed so as to give the correct scale to the picture. An airplane containing these features has recently been designed by Talbert Abrams of Abrams Aerial Survey Corp. of Lansing, Michigan. This plane is of the pusher type and the nose is all glassed in so as to give maximum visibility. This plane is capable of gaining an altitude of 20,000 feet in 20 minutes--200 miles per hour.

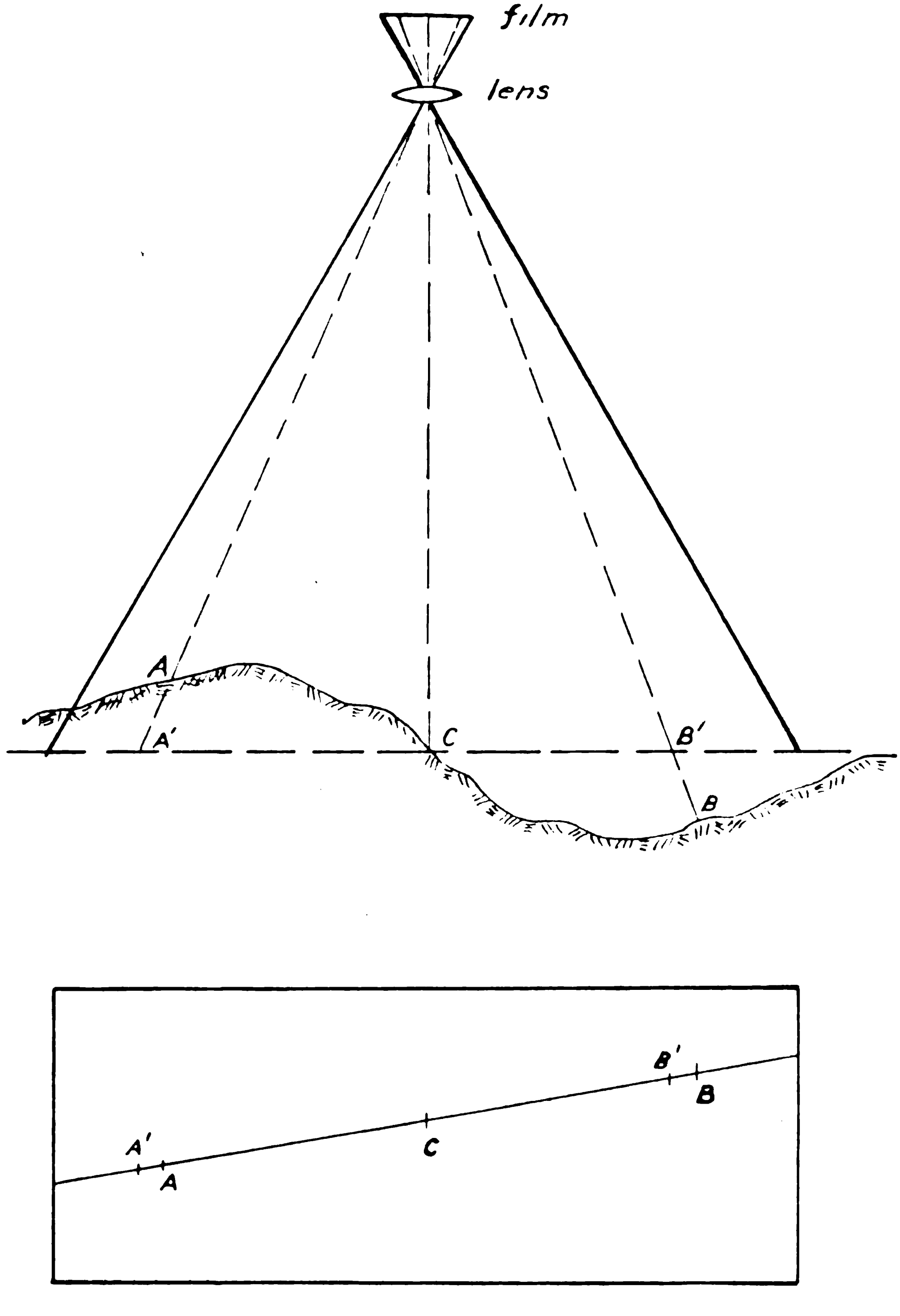

Fig. 2
DISPLACEMENT

R.O.S.

PHOTOGRAPHING

In making the photographs the personnel must be highly specialized. As the airplane flies at altitudes between 20,000 and 25,000 feet the pilot and photographer must wear oxygen masks. As this work requires that the men be on their toes all the time, they do not depend upon the thin air at these altitudes for their oxygen, as it is insufficient.

There are two general classes of aerial photographs--vertical and oblique. Vertical photographs (Plates I & II) are made from any altitude with the axis of the camera lens perpendicular to the ground, that is, with the camera pointed straight down. Oblique photographs are made from relatively low altitudes with the axis of the camera deviating from the vertical to a pronounced extent, the best results being obtained when the axis of the camera lens is inclined approximately 30 degrees from the horizontal. The **oblique** photograph is the more artistic and pleasing of the two, and gives one a splendid idea of the terrain pictured. Buildings, roads, streams, etc. stand out clearly in perspective, but the photograph is not to scale. It is because of this last reason that only vertical photographs are used in mosaic and index maps which are to be used as surveys.

The photographs are taken in flights. The pilot sets a course and flies in a straight line at a constant speed as the photographer takes the pictures. The pictures

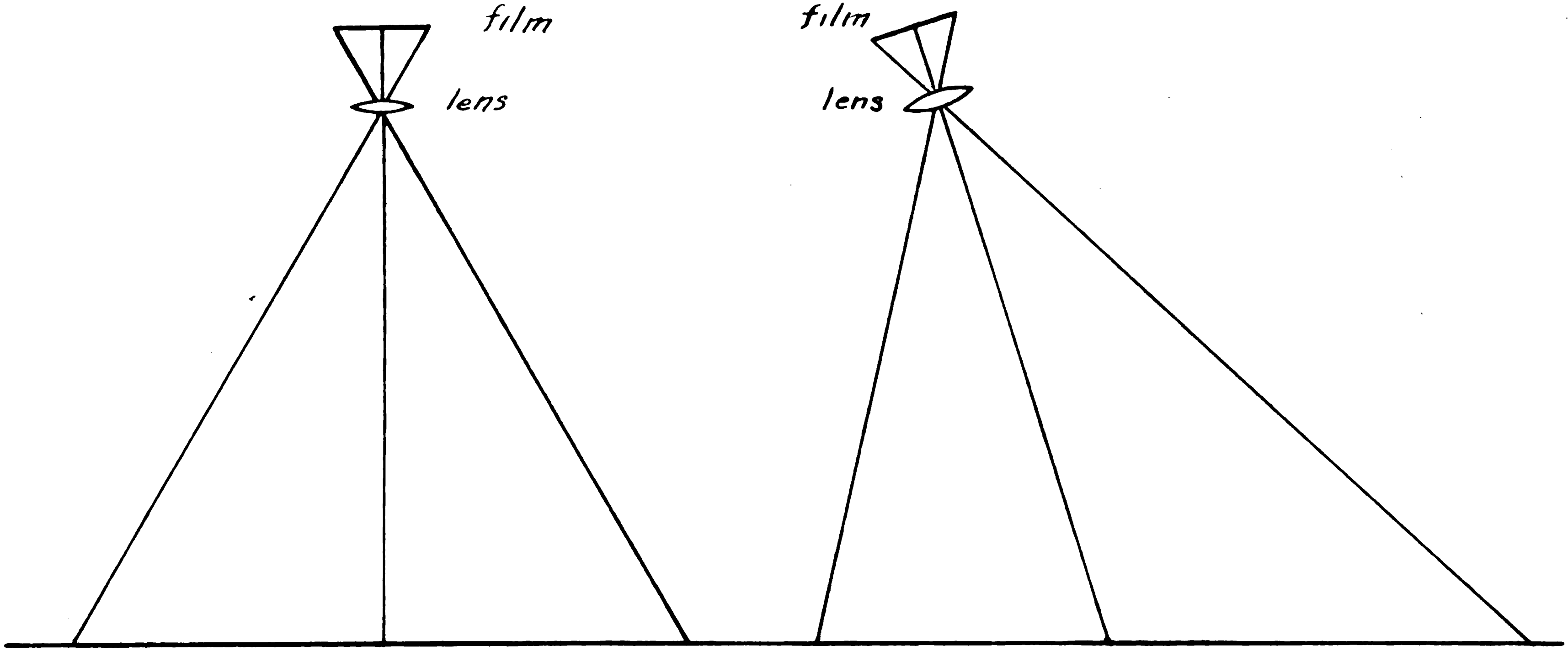

Fig. 3
EFFECT OF TILT

R.O.S.

in the flights are taken at such an interval so as to give a 60 per cent overlap (Plates 1 & 2). Each flight overlaps the previous flight (side lap) about 50 per cent. This overlap allows for the distortion at the edge of prints and one can also use radial control when assembling the map as each control point is on three prints. The overlap between flights also allows for a small amount of drift the plane might make from its straight line course.

Each roll of film is labeled as to flight and area after exposure. The film is then taken to the laboratory where it is developed by methods similar to other photographic developments except more care is taken in the process. After the film is dried and each print is labeled it is ready to be printed. Each negative on the roll makes a separate print. This is done by placing each print on the printing machine in order and exposing it to sensitized paper. The source of light for exposure in this machine is from a group of light bulbs below the glass on which the print is made. Each bulb is controlled by a rheostat, thus enabling the operator to control the intensity of light on different parts of the negative. This blends the shade of the print, so as to give a clear cut photograph.

In exact mapping work a distortion corrector should be used. The distortion corrector is an exclusive invention of Talbert Abrams. Before this invention, it was impossible to produce a photograph made with a lens where the distance to the object was greater than the focal length of the lens without multiplying scale error as the distance expands from the center of the negative. This is called paralax or distortion due to change in elevation or tilt of either the camera or the ground, and angular displacement of ground objects due to the curvature of the lens. These distortions are corrected in this machine by fastening the print on the inside curve of the bowl and projecting it on sensitized paper. The curve of this bowl matches and offsets the curve of the lens. Thus a map photograph can be produced with accurate scale even at the extreme edges.

There are several types of projectors used to make the finished print. The most common is the one that makes the print the same size as the negative which has been discussed previously. Other projectors used vary the size of the print. The negative is put in the projector and is projected on sensitized paper either larger or smaller than the original.

INDEX MAP

After the prints are finished they are made either into an index map or a mosaic. An index map is made by laying the pictures in the order they were taken overlapping both in line of flight and sidewise. This gives a map with index numbers on each print. This index map is then photographed (Plates 1 and 2). The negative and prints of this index map are then filed away for future use. When a question arises about some portion of the map a look at the index map will tell, from the index number which print is needed. The original print is then found from the files in a short time.

MOSAIC MAP

The mosaic method of mapping differs decidedly from the index map. In a mosaic the series of photographs are fastened together so as to form a composite picture. When the prints are oriented by matching details, it is called an uncontrolled mosiac; when they are oriented by means of selected points of each print they are controlled mosiac. These points are control points. A semi-controlled mosaic is when the prints are laid on a straight that passes through the principal points of each photograph. Radial control is accomplished by locating a point in the center of each photograph, one near each corner, and a point near the center of each side of the print. The outer points are connected to the central control point by radial lines.

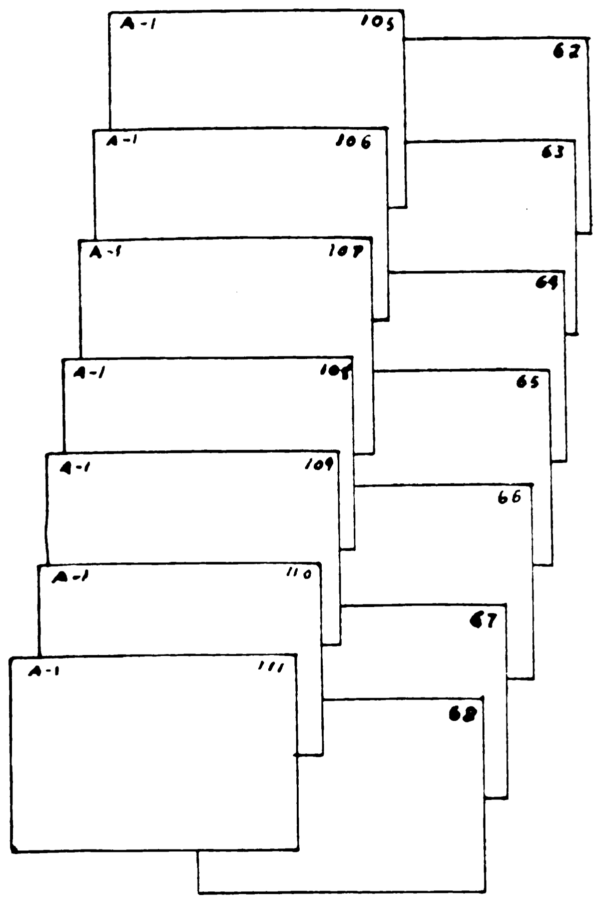

Fig. 4

INDEX MAP

R.O.S.

Then by use of slotted or scratch tempelets the prints are oriented and ready for laying.

In laying the mosaic care must be taken to lay to color, contour, and match. On different prints an object might appear in two slightly different shades. The two prints must be cut and lain so as not to show a difference of color from one to the other. The objects must also be cut to match. In the case of a very irregular terrian the photographs should be cut on the contour so as to show distortion or displacement. At the same time the color and the match should be controled.

The finished mosaic is then photographed to the desired size. The negative of the mosaic is then touched up so as shades out the lines where it was put together and to fix slight color differences. The negative is then printed giving a map all of one piece and with all the details complete without showing how it was put together.

STEREOSCOPE

The sterescope enables one to see the picture in three dimensions. This consists of two photographs of the same object or terrain, taken from slightly different positions. The area in the 60 per cent overlap of two consecutive pictures constitute a stereoscopic pair (Plates 1 and 2). The photographs can now be viewed through a mirror stereoscope (Fig. 5). The object seen will be in three dimensions. It will show not only length and width but also the heighth. The explanation is fairly simple. As our eyes are approximately 2½ inches apart each eye views an object from a different point of view and obtains a slightly different image. The merging of these two images by the stereoscopic power of our eyes gives us a distinct impression of depth. This is what is accomplished with the stereoscope. The camera acts as the eye getting a picture of the image from two different views. Then with the aid of the stereoscope we are able to get the third dimension.

CONTOUR FINDER

The contour finder is a stereoscope with a few additions. The contour finder consists of the following: a folding single lens magnifying stereoscope, micrometer adjustment for measuring paralax, drafting arm for scribing contours, and drafting board with swinging arm adjustment to hold the contour finder in adjustment, while the micrometer adjustment for measuring paralax consists

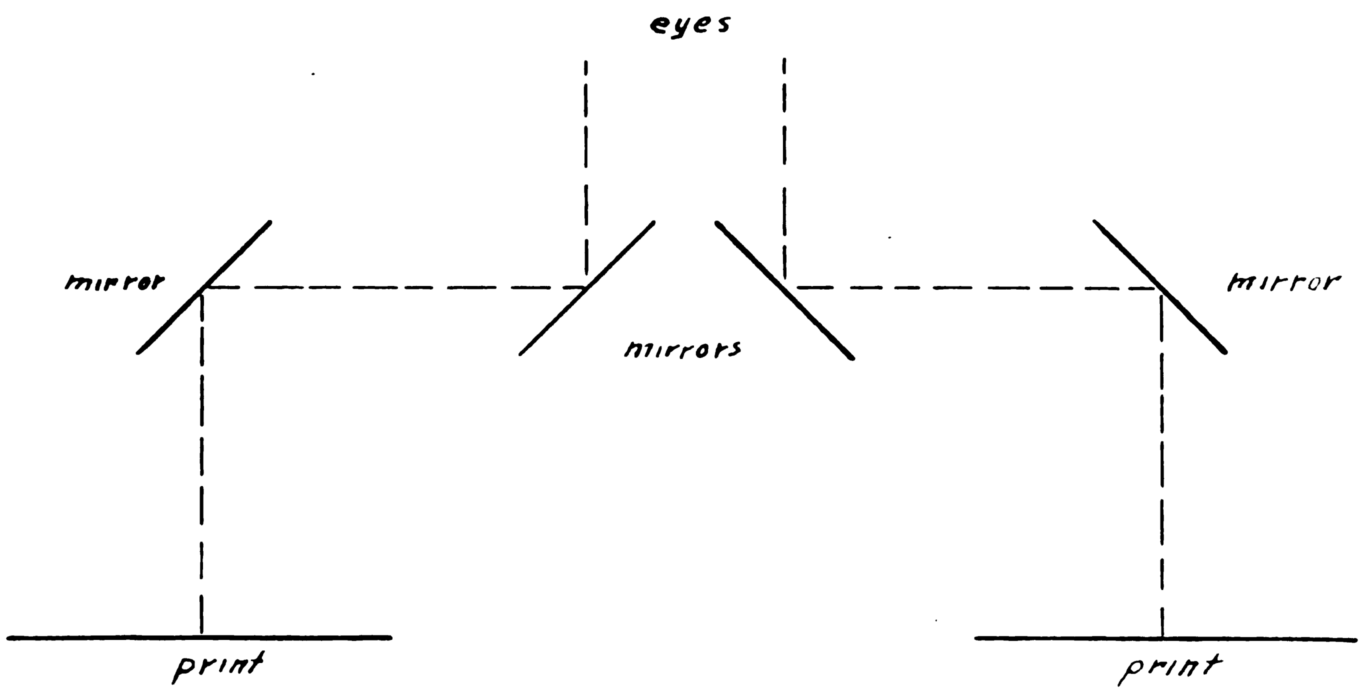

Fig. 5

STEREOSCOPE

R.O.S.

of two glass slides with a dot in the middle. These slides fit in a frame and the right one can be moved by the micrometer adjusting screw. Place the two dots on the same object on their respective print. Now look through the stereoscope and adjust the right dot until the dots appear as one and at the level of the ground. Read the micrometer. Next move the right slide until the dot appears at the top of the object and again read the micrometer. This difference in reading multiplied by a factor gives the height of the object. This factor is obtained by actually measuring the height of the object and dividing by the height found with the contour finder. The drafting arm and drafting board are used to scribe the contours on the same print or duplicate prints of the same size or even larger or smaller. This method of contouring was designed by Talbert Abrams and is very accurate.

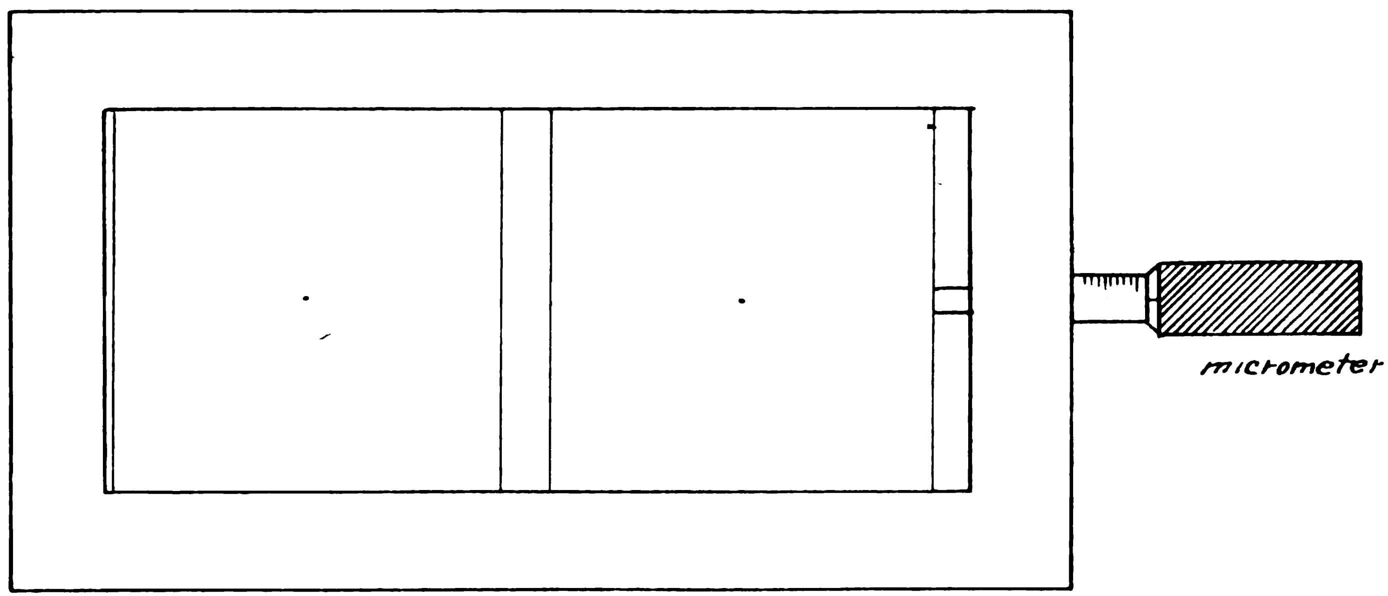

Fig. 6

CONTOUR FINDER

R.O.S.

Part II

Mapping from Vertical Air Photographs

MAPPING FROM VERTICAL AIR PHOTOGRAPHS

The following pages give a brief description of the method of mapping by means of the Topographical Stereoscope, known as the "Arundel" method. As the principle is the same in each Stereoscope, a description of the steps necessary for the production of a map by one type of Stereoscope will be sufficient.

The method of plotting consists of fixing a control on the first overlap of a strip of vertical air photographs and intersecting this control, this intersected control being then used to resect the position of the next photograph, and so on throughout the strip. A strip of vertical air photographs consists of photographs exposed at regular intervals along a straight flight, giving an overlap usually about 60%. Before any system of intersection can be applied, it is necessary to find some point on the photograph from which directions can be transferred direct to the plot. Except in the case of a perfectly vertical picture of flat country, the photograph will not be of a uniform scale, so that it is obvious that any point will not serve the purpose.

In the "Arundel" method the point chosen is the principal point and it is assumed that angular measurements from this point of a nearly vertical photograph are equal to the horizontal angles between corresponding points on the ground. This assumption is justified for photographs of tilt not more than 2°; therefore it is essential to have good level flying. It is also necessary to have a rapid means of detecting accidental tilts, so that any errors due thereto can be rectified by a closer ground control. This is accomplished by drawing a "Minor Control Plot" as described later.

The "Arundel" method is intended only for the surveying of areas where <u>differences</u> of ground heights do not exceed one-tenth of the flying height. Where differences exceed this amount the "Clova" method is used and in this method it is necessary to determine the absolute vertical or plumb point, the "Clova" method assuming that the angular measurements from the plumb point are equal to the horizontal angles between corresponding points of the ground.

Accurate maps on a scale of 1/20,000 can be produced by these methods.

SUMMARY OF METHOD

The steps in the process may be summarised as follows. Details of each step are given later.

A. Mark principal points on all photographs to be used.

B. By means of the Topographical Stereoscope draw principal point base or line of flight.

C. Decide on minor control points, two per photograph, and draw radial lines from principal points to intersect minor control points. Each minor control point should appear on three successive photographs.

D. Draw a minor control plot on a suitable tracing medium.

E. Analyse the minor control plot to find tilts.

F. Mark on the photographs information obtained by ground parties.

G. Draw contours on every second photograph by means of the Topographical Stereoscope.

H. Plot on the minor control plot tracing the desired detail from the photographs.

I. Reduce minor control plot and added detail to required scale by photography.

J. Make bromide prints for final fair tracings.

DETAILS OF STEPS

A. Mark the principal point on each photograph throughout the strip, the principal point being the centre of the photographic plate, or, more correctly, the foot of the perpendicular from the rear nodal point of the lens to the photographic plate. Some aerial cameras record on the edges of each plate two small horizontal and two small vertical lines, known as collimating marks, and if these are joined, they will cross at the principal point of the photograph. If these lines are not available or if the principal point is not otherwise indicated, it can be obtained by intersecting portions of the diagonals.

B.1- Place the first two photographs of the strip one over the other on a flat table, as if they were to be joined in a mosaic, the overlapping portion common to the two photographs being roughly in coincidence. Turn both photographs round together until the run of shadows falls as far as possible away from the source of light under which they are to be examined. In this position the print to the left willbe placed on the left turntable of the Topographical Stereoscope and will be seen with the left eye.

2- Adjust the left grid of the Topographical Stereoscope until one of the vertical lines on the base line (that is, on the horizontal centre line of the grid) is exactly in coincidence with the centre of the left turntable.(Fig. A) Accurately adjust the corresponding line on the right grid to the centre of the right turntable without moving the left grid.

3- Without looking through the eye-holes of the stereoscope, place the left photograph below the left grid so that the principal point lies exactly below the vertical line selected on the grid (i.e. so that the principal point is exactly on the centre of the turntable), and rotate the photograph until a point of detail which appears close to the principal point of the right photograph lies approximately on the left grid base line.

4- Similarly, fix the principal point of the right photograph above the centre of the right turntable and rotate the photograph until a point of detail which appears close to the principal point of the left photograph lies approximately on the right grid base line.

5- Fix both photographs by means of the clamps supplied.

6- Choose a particularly distinctive object, which appears on both photographs, and observe this object through the eye-holes of the stereoscope. Adjust the two small mirrors by turning the milled head at the front of the mirror framework until the selected object can be seen stereoscopically without straining the eye.

7- Observe the grid stereoscopically as well as the ground, although not concentrating on the grid, and it will be seen to rise and fall in relation to the ground as the right grid is moved longitudinally. Displace the left grid until one of the intersections of the N.E. and

N.W. lines lies over a point of detail at the principal point, or slightly to the left of the principal point, of the left photograph.

8- Displace the right grid until the intersection, or what appears to be the lower line of the intersection, lies just above the point of detail selected on the left photograph.

9- If both cross lines do not appear to touch the ground at the point of intersection, the orientation of the right photograph is at fault. To correct this, rotate the right turntable very slowly until both cross lines appear at the same depth when just above the point of detail being observed.

10- Similarly, correctly orient the left photograph by observing on a grid cross set on the right principal point or slightly to the right of the principal point.

11- To mark the principal point base, raise the left grid, place the steel straight edge against the stops provided, and draw a thin line from the centre of the photograph to the right edge. This line is also drawn backwards to the left to form a tail at the edge of the photograph. Raise the right grid and, again by means of the straight edge, draw a line from the centre to the left edge and also mark the tail on the right edge.

12- Transfer the right picture to the left turntable, place the next picture on the right table and in a similar manner obtain the principal point base - or line of flight, as it is also called. Continue doing this until the line of flight has been drawn along the whole strip.

C.1- Choose two points of detail A, B, in the small overlap common to the first three photographs, so that p1p2, p2A, and p2B are all approximately equal, and such that Ap2B is nearly perpendicular to the principal point base p1p2. (Fig. B - 1)

Note: In this and subsequent paragraphs, the principal point of any photograph is designated by the letter "P" and a numerical suffix. With this notation P3 is the principal point of the third photograph of a strip. Similarly, the point of the third photograph, say, corresponding to the princiapl point of the second photograph is designated by P2.

2- Identify and prick with a fine needle the points A and B on all three photographs. Similar points C and D are then chosen on the second, third and fourth photographs and so on throughout the strip. These points are known as minor control points.

3- Draw short lines through the minor control points from the principal point of the photograph on which they appear.

4- Ink in red or orange the short lines passing through the minor control points and the principal point bases and their "tails". Any photograph, after the first two at either end of the strip, should now contain six minor control points, furnished with short radial lines and two base lines complete with "tails."

D.1- Cut a strip of matt-surfaced drawing celluloid to sufficient length and breadth to include the whole strip of photographs.

2- Place the first photograph under the celluloid in such a position and orientation as to confine the whole strip plot to within the limits of the sheet of celluloid.

3- Fix the first photograph of the strip and celluloid down flat by drawing pins.

4- Prick through the points A and P1.

5- Trace in light blue ink the radial directions of B and the first principal point base P1P2. (Fig. B)

6- Remove the first photograph and replace by the second photograph, placing it so as to make P1P2 coincide in direction with the tracing P1P2. (A good fit is obtained as the red or orange lines on the photographs show an unmistakable heliotrope when in perfect coincidence with the blue lines on the celluloid). Still maintaining this orientation, move the tracing over the print until the radial direction to A passes through the pricked position of this point.

7- Fix down the tracing securely, prick through the principal point P2 and trace the radial directions of B, C, D, and of the next principal point base P2P3. B has thus been intersected on the scale of the plot

8- Place the third photograph under the tracing, orient along the principal point base P2P3 - P2P3 and slide along this common direction until the radial direction to A passes through the plotted position of this point. The radial direction to B should now pass through the plotted position of B.

9- Trace in the radial directions and principal point base and continue until the whole strip has been traced.

The minor control plot thus drawn is a plan of the minor control points and principal points on an unknown uniform scale. The scale of the plot is actually the local scale of the first photograph in the vicinity of the minor control point A. It is best to commence the plot at approximately the same scale as the area of heaviest detail. As such an area may occur at any part of a strip, the minor control plot need not therefore be commenced at the first photograph but could be commenced at any part of the strip and built up by working in both directions.

It will be seen that no check is available on the position and orientation of the second photograph, while the third and succeeding photographs are each checked from two other photographs.

E. As the photographs are taken on a fixed time interval, the plotted positions of the principal points will be equally spaced along a straight line, provided the flying has been good.

1- If the principal points are not equally spaced this is probably due to fore-and-aft tilt.

2- If the principal points do not lie on a straight line, this may be due to departure from a straight course or due to lateral tilt.

The presence of tilt in photographs of comparatively flat country can be checked in the Topographical Stereoscope by means of the grids. If tilt is present, the grid will appear deformed and its deformity relative to the ground at any point and in any direction affords an indication of the tilt.

Where tilt is found, it is necessary to have a good ground control.

F. If no tilt has been found from the minor control plot, a single strip of vertical photographs may be plotted without ground control. Relative errors of position and orientation may occur within the strip plot, but the detail will be true to shape and the result may often be all that is necessary for many purposes.

For more accurate work and to prevent an undue accumulation of error, it is necessary to provide a network of fixed positions surveyed on the ground.

From information obtained from the ground parties:

1- Locate and mark, with a green dot on the photographs, the position of all measured heights. Mark the actual height beside the dot.

2- Locate and mark on the photographs all other positions which have been surveyed on the ground.

3- Draw short colored radial lines through these positions in the same manner as for the minor control points.

(On very steep slopes the shape of the ground detail will appear quite different on the two photographs. Corresponding points for intersection should in that case be identified and marked in the Topographical Stereoscope).

G. Once a network of heights has been fixed by measurement, the actual contours are best interpolated in the Topographical Stereoscope, the whole area of an overlap being examined at one time. Further heights can be obtained from the photographs by taking parallax measurements with the Stereoscope. Where tilt is not considerable and an unknown height lies between two known heights, it may be assumed that differences in parallax are directly proportional to differences in height.

Parallax differences are measured in the Precision Topographical Stereoscope as follows:-

(a) Take one of the vertical lines of the left grid alongside, but not actually touching, one of the points whose difference of parallax is to be measured and then move the right grid until the fused line appears to lie at the same depth as this point.

(b) Note the reading of the scale.

(c) Turn the left working head until the line on the left grid lies alongside the second point to be observed and then move the right grid until the fused line appears to lie at the same depth as the second point.

(d) Again note the reading of the scale. The difference between the two readings is the required difference of parallax.

With a little practice parallax readings to 0.02-mm can be obtained.

This system can also be applied to photographs which are considerably tilted, subject to certain limitations.

A modified and somewhat complicated procedure may be used where the unknown heights do not lie between known heights, by making a calculated allowance for the influence of tilt on parallax.

Having obtained additional heights, as described in the foregoing, contouring can be done my means of the Stereoscope.

The contours are drawn on every second photograph only, the intermediate overlapping photographs being used only to provide the necessary stereoscopic impression.

H. Detailed plotting can be done on the minor control plot between the intersected positions of the control points or between a closer intersected control. Tracing of detail between the intersected control is carried out by fitting triangles, that is, the areas within sets of three control points.

As a check, the points surveyed on the ground should be marked on the photographs and short radial lines drawn through them as previously described. These points should also be drawn in their correct positions on the minor control plot to the mean scale of the photographs.

The plotted positions of the ground control points should be compared with their true positions. Any discrepancy between them will indicate the amount by which the plotted positions have to be shifted and the detail can then be traced from point to point.

Cases may arise where sufficient ground control already exists to enable the photographs to be used for detail plotting without drawing a minor control plot. The ground control points (which should not be fewer than four per photograph) are then plotted at the mean scale of photography on a sheet of drawing celluloid.

The lateral strips are usually flown so as to give a lateral overlap of about 30% and in compiling a map the lateral strips are joined through this overlap.

I. By photography reduce the minor control plot and added detail to the desired scale, due allowance being made for the shrinkage of the paper prints.

J. Make fair tracings from the bromide prints supplied from the photographs.

Blocks for printing the various colors required on the final map are made from the fair drawings and a blue "pull" is taken from the block containing the outline of the country, rivers, roads and position of towns. To this "pull" are added the names of the various towns, rivers, etc.

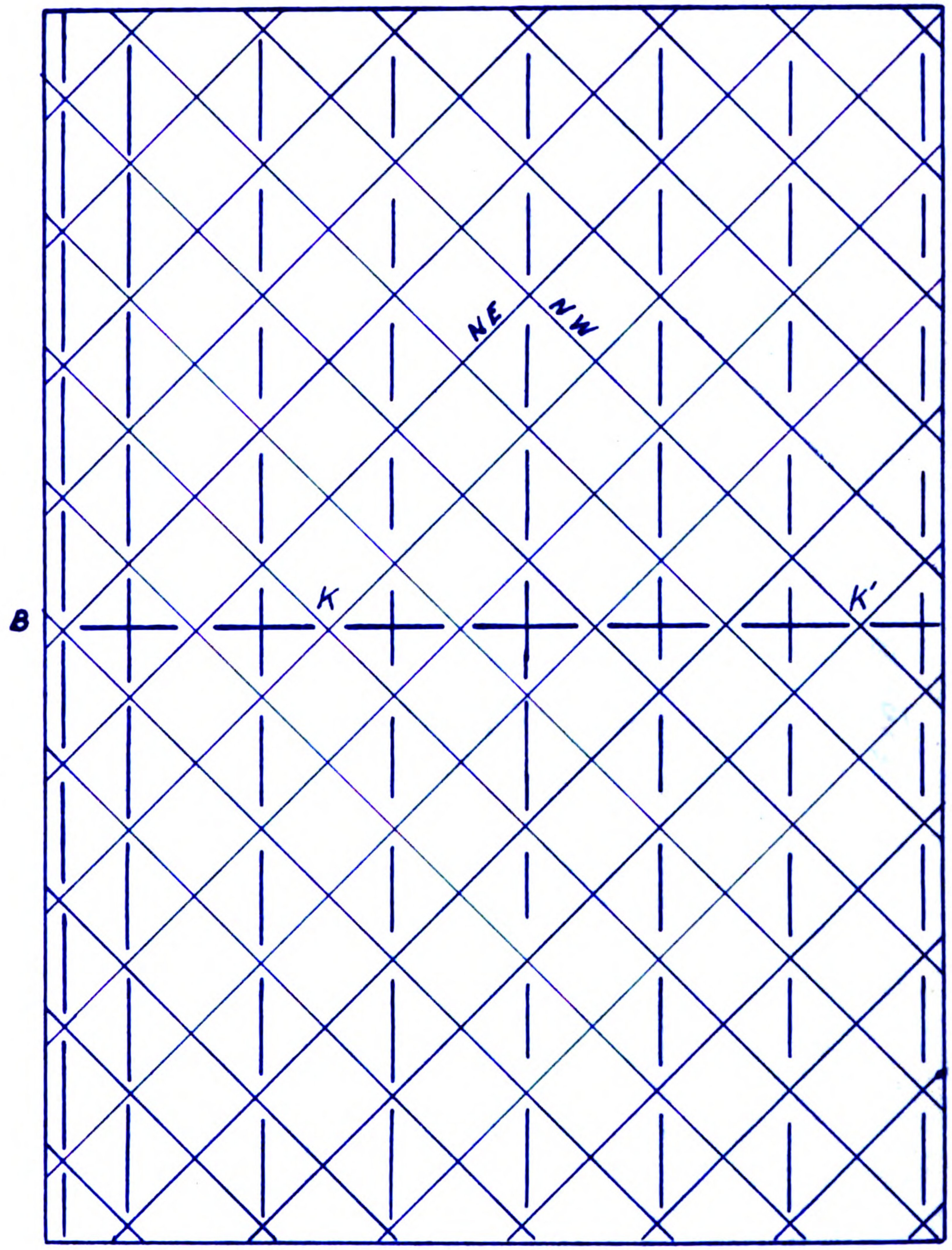

Fig. A

R.O.S.

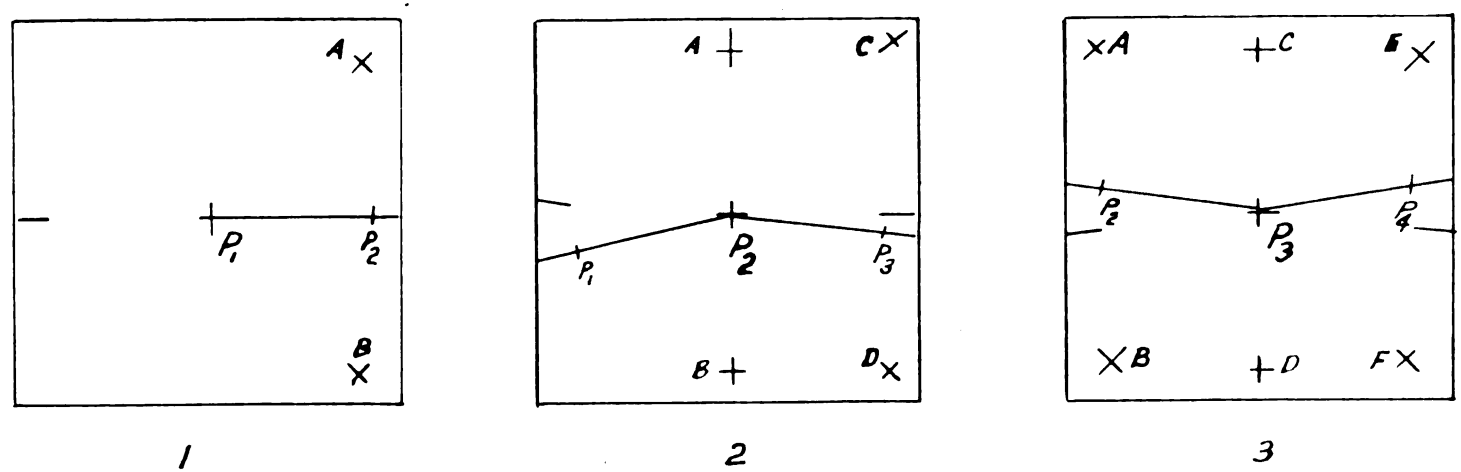

Fig. B

R.O.S.

[redacted]

Nov 8 '39


3-1-38
Plate II
AOL-4- 91
AOI-
Abrams Aerial Survey Corp. Lansing, Mich.

3-1-38
Plate I
AOL-4-90
Abrams Aerial Survey Corp. Lansing, Mich.

Pocket has: Plate 1 & Plate 2