DEPARTMENT OF THE INTERIOR
Hubert Work, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Bulletin 788—F

TOPOGRAPHIC INSTRUCTIONS OF THE UNITED STATES GEOLOGICAL SURVEY

F. MAP COMPILATION FROM AERIAL PHOTOGRAPHS

By T. P. Pendleton

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1928

NOTE

It is desired that these instructions shall be complete so far as the compilation of small-scale maps from aerial photographs is concerned, in order to reduce to a minimum the necessity for personal instruction in such work. Notice of errors or omissions and suggestions for improvement will be welcomed.

C. H. BIRDSEYE,
Chief Topographic Engineer.

Approved:
GEORGE OTIS SMITH, *Director.*

WASHINGTON, D. C., *May 15, 1925.*

CONTENTS

ILLUSTRATIONS

F. MAP COMPILATION FROM AERIAL PHOTOGRAPHS

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INTRODUCTION

The value of photographs for map construction was appreciated immediately after the invention of the camera, and many methods of utilizing photographs made from ground stations for this purpose have been perfected, but until some time after the development of the airplane no attempt was made to use aerial photographs in this way. No effort is made to describe here any of these older instruments or processes, nor methods of compilation other than those used by the Geological Survey.

As considerable experimentation on the design of instruments and the development of a compilation process that will utilize advantageously aerial photographs for mapping has been carried on, it seems advisable to describe the instruments and methods now in use by the Geological Survey, recognizing the fact that they may soon be supplanted by newer and better ones.

INSTRUMENTS

SINGLE-LENS CAMERA

The single-lens camera most commonly used is shown in Plate 24 in a dummy installation and is often called the "K" type, the several models being denoted by numbers as "K–3." This camera is entirely automatic and is so designed that the interval between exposures may be varied from 4 seconds to over 1 minute. It is equipped with an anastigmat lens having a maximum stop opening of f/4.5 and a focal length of 12 inches. The shutter is of the "between the lens" type and gives exposures of 1/50, 1/100, and 1/150 second. Photographs 18 by 24 centimeters are made on roll film about 75 feet in length, sufficient for about 120 exposures. The camera is motor driven, power being provided by a storage battery, and may be loaded during flight, as the magazine with the exposed film may be removed and another containing unexposed film quickly substituted.

The intervalometer controlling the intervals between exposures having been set to give the desired overlap of photographs, the motor will trip the shutter, count the exposure, remove the pressure of the film-pressure plate, wind an unexposed portion of the film into position, replace the film-pressure plate so that the film is held in close contact with the glass focal-plane plate, and set the shutter ready for the next exposure. The camera is suspended in gimbals that allow it to be rotated about its vertical axis and to be leveled in the focal plane. A horizontal position of the focal plane is indicated by a circular level attached to the camera.

RECORDING CONE

The latest model of the single-lens camera is the K–8 type. This camera is in certain minor details simply an improvement on earlier models, but the recording cone used with it is unlike anything that has been introduced heretofore.

The purpose of this recording cone is to register photographically on the negative, at the moment of exposure, all pertinent data concerning it and thus provide positive identification for each photograph. This is accomplished by photographing on the edge of the negative a watch face, a circular spot level, an altimeter, a mechanical counter, and a card on which any data concerning the flight may be written. This device is set in a door in the side of the lens cone and functions just after the camera exposure has been made and before the film is wound forward. The photograph of the recording device is easily read, although it occupies a space but 10 by 38 millimeters, and as it appears along one edge of the print it does not interfere with the usefulness of the print in the least.

MULTIPLE-LENS CAMERA

Multiple-lens cameras of the type so extensively employed at present in the photographic mapping of this country have many advantages due to the large area photographed at each exposure. These advantages are so great that they more than offset the slight indistinctness often encountered at the outer edges of the photographs. This lack of definition does not result from lack of perfection in the construction of the camera, but is caused by the distance and angle at which the objects in this portion of the field are viewed and by the transformation that these oblique views must undergo in preparing them for use in mapping. During the last few years there has been a remarkable improvement in the quality of photographs of this type and it is not too much to expect that this improvement will continue until they are entirely satisfactory.

The multiple-lens cameras are constructed with either three or four lenses each. The four-lens or T–2 camera is an improvement on the tri-lens or T–1 and will probably soon supersede it on account of the increased ease and accuracy of map compilation that it makes possible.

The four-lens camera consists of four sections, two of which are film magazines containing the rolls of film and two contain the lenses and dark chambers of the camera proper. This instrument can be considered a tri-lens camera to which has been fitted an additional, detachable lens unit.

The object in designing the multiple-lens camera was to include a larger field of view at right angles to the direction of flight of the airplane than is given by any photographic lens of large light-gathering power. This was accomplished by fixing the central lens with its axis in the vertical position while the axes of the other two lenses were in the same plane but at an angle of 35° to the left and right. The combined field of view in the plane of the lens axes is 115°, which leaves a liberal margin of overlap of fields for matching the photographic prints. This overlap can be most clearly visualized by considering the two oblique lenses as located in the same position as the central lens, as shown in Figure 13, an assumption which is permissible, as the actual separation is only a few inches. The maximum angular field of view and the amount of overlap differ slightly in different cameras, owing to the small differences that exist in the focal lengths of the lenses selected for each camera.

Front and rear views of the T–2 camera are shown in Plate 25. In the front view the line of division of the upper and lower portions of the camera can be easily distinguished. The base contains three lenses, dark chambers, and focal-plane surfaces. The three lenses and their corresponding focal planes are distinguished by the letters A, B, and C. The compartment for the fourth lens is accordingly called the D compartment. The A, C, and D focal planes make an angle of 35° with the focal plane of the B compartment. A view of the focal planes is shown in Plate 26, *A*. The center (B) compartment contains two level vials, so placed that an image of the bubbles will photograph on the negative when the exposure is made. The four index marks that appear at the edges of each focal plane play a very important part in the use of the photographs. The intersection of the lines defined by these indexes is the "principal point" of the negative and marks the intersection of the optical axis of the lens with the focal plane.

Rollers are provided at each end and between the focal planes to reduce the friction encountered in winding the film into position. The lenses have a focal length of about 7.5 inches for the A, C, and

D chambers and are matched at the factory to about 0.10 millimeter in order to insure equality of focal lengths. This agreement of the focal lengths of the oblique lenses renders the transformation of the negatives a relatively simple matter. The B compartment is equipped with a lens having a focal length of about 6.5 inches, as this shorter focal length permits the construction of a much smaller camera than would otherwise be possible. The lenses have a maxi-

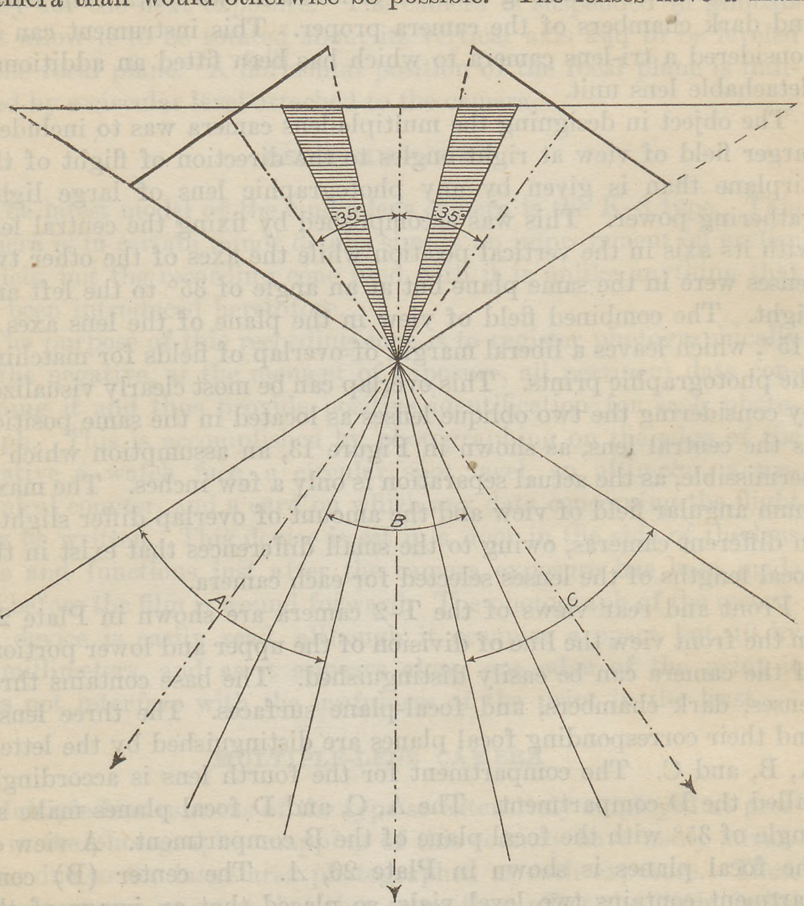
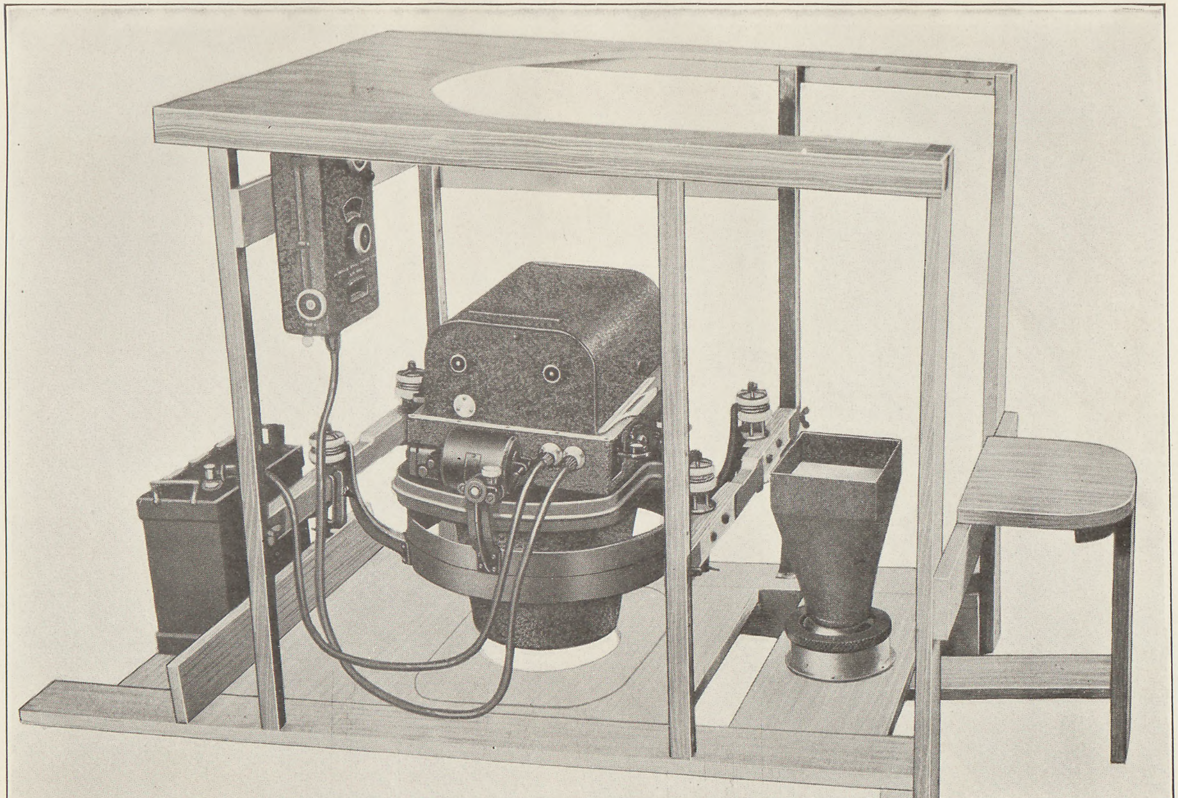


FIGURE 13.—Lateral field of view of T-1 camera

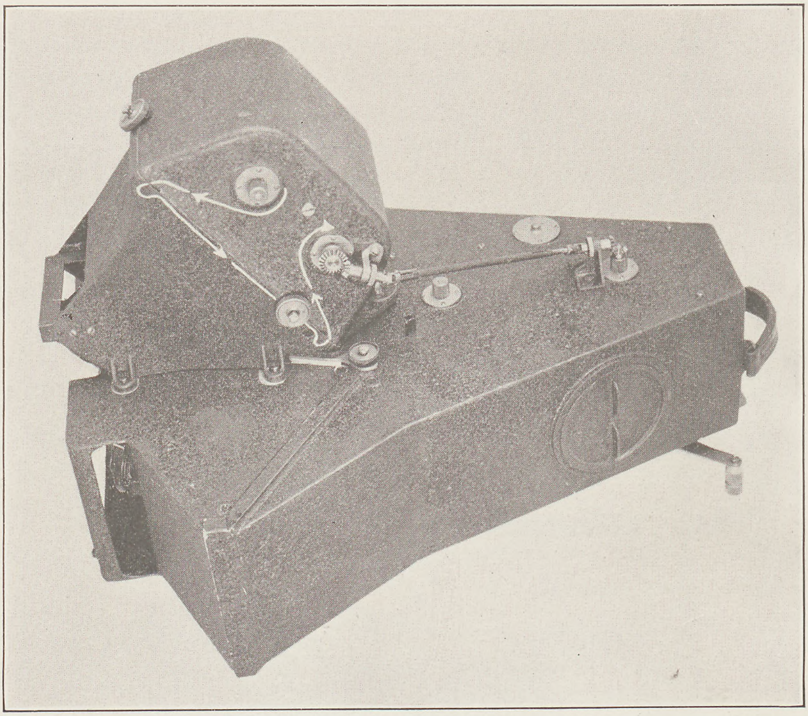
mum stop opening of f/4.5 and are mounted in "between the lens" shutters. The arrangement of the lenses and the shutter-release mechanism are shown in Plate 26, *B*. As it is essential that the four lenses be exposed at the same instant, provision is made whereby the shutters of the oblique lenses can be synchronized with the shutter of the central lens.

The upper or magazine section of the camera can be detached from the base by loosening four clamp screws, two of which are

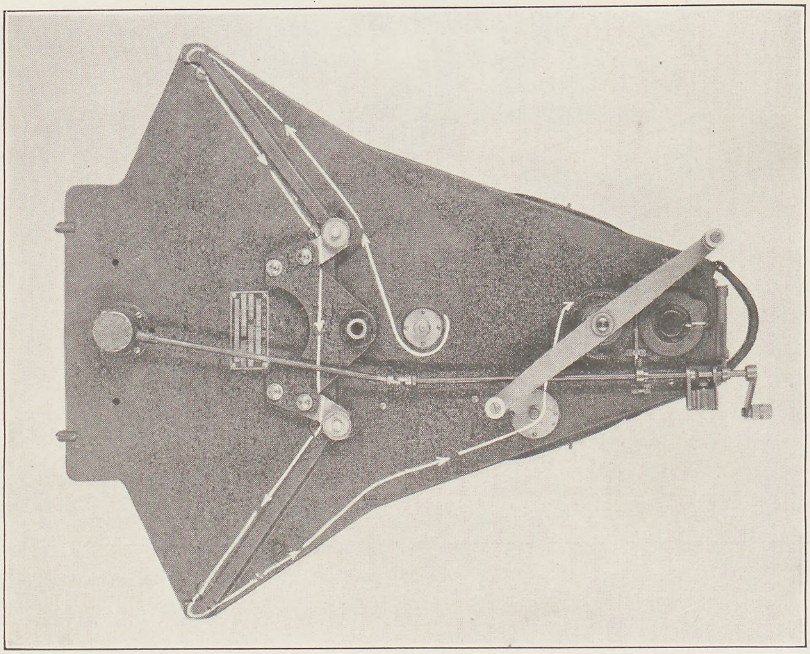


A SINGLE-LENS CAMERA

Photograph used by permission of Fairchild Aerial Camera Corporation



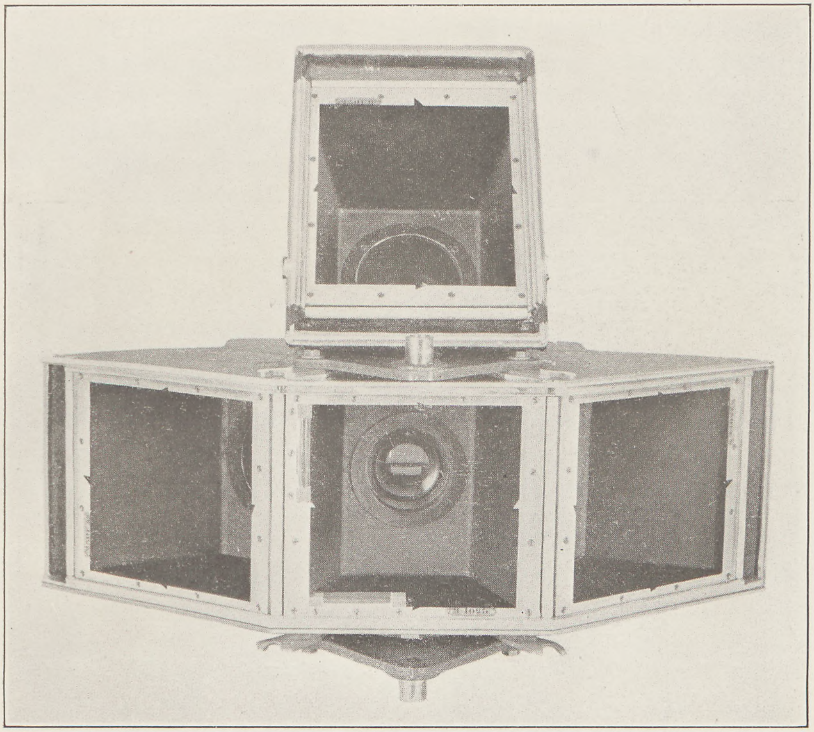
A



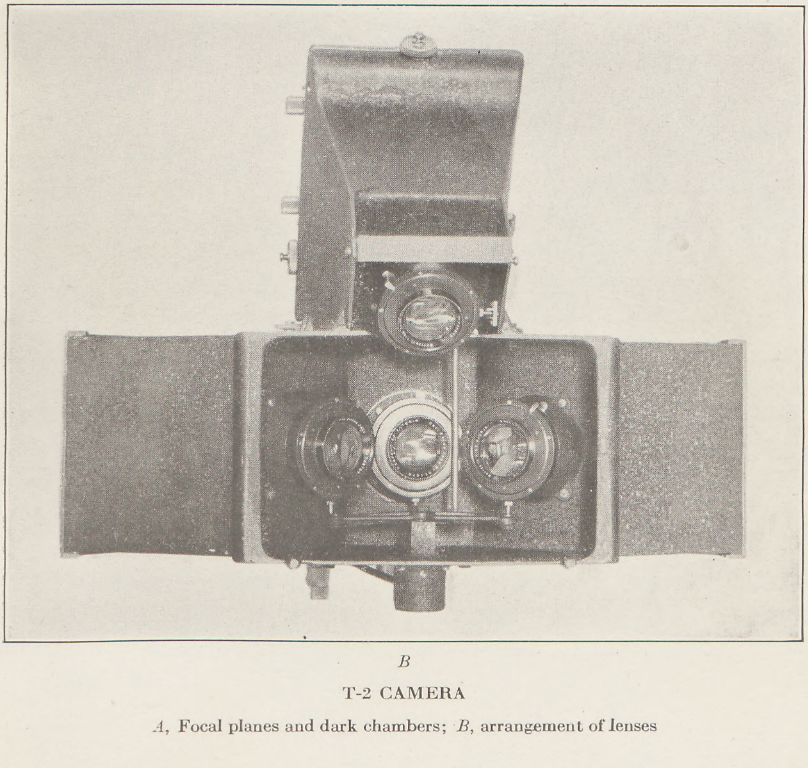
B

T-2 CAMERA

A, Rear view; *B*, front view



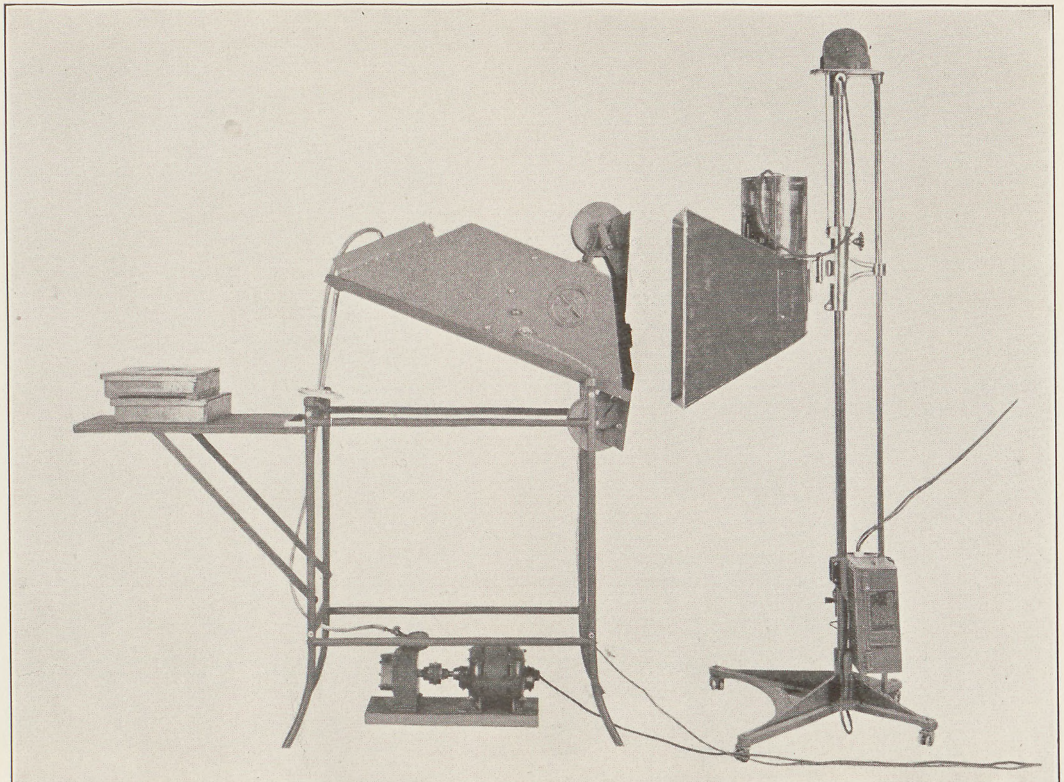
A



B

T-2 CAMERA

A, Focal planes and dark chambers; *B*, arrangement of lenses



THE FIXED T-2 TRANSFORMING PRINTER

shown in Plate 25, *B*. The two film-carrying spools are so mounted that they are on the vertical axis of the camera, with the take-up spool above the full spool. The film must be wound onto the empty spool by the hand crank shown in the illustration, as this camera is not of the automatic type. The film is guided in its journey from one spool to the other by several guide rollers in the magazines in addition to those in the base. The proper amount of film to be wound forward between exposures is indicated by one revolution of the dial shown above the hand crank in Plate 25, *B*. The film is held in the focal plane by three spring pressure plates which are provided with stops that prevent the pinching of the film between the focal planes and the pressure plates. The plate back of the B compartment is removable to facilitate the loading of the camera in the dark room. Two handholes with light-tight covers are provided on the sides of the magazine section for the same reason. The top of the camera is fitted with two level vials to aid the observer in keeping the camera in an upright position at each exposure and with an exposure counter and stop watch for recording the number and indicating the instant of each exposure. These devices are actuated by cams and gears on the shaft of the shutter-release mechanism.

The D unit of the T–2 camera is attached to the base of the camera on the side opposite the hand crank, with its optical axis at an angle of 35° with that of the B chamber. This arrangement places the focal plane of this unit at the same angle with the B plane as is made by the A and C planes and furnishes a photograph of the region back of the airplane. It is equipped with a lens identical in all respects with the A and C lenses, but has an independent film chamber and two film spools. The relation of this unit to the rest of the camera is shown in Plates 25, *A*, and 26, *B*. The shutter is synchronized with and actuated by the same mechanism as the B shutter, and the film is wound into position by the hand crank of the camera by an arrangement of bevel gears and a universal-joint shaft, also shown in Plate 25, A.

This camera uses hypersensitized panchromatic film in a roll 6 inches wide by 380 feet long, which is sufficient for 190 tri-lens exposures, and a shorter roll of the same width for the D unit. As this film is sensitive to light of all colors, it is necessary to load the camera in total darkness, and as its keeping quality is not good it should not be ordered until needed for use. It is kept under refrigeration at other times.

Color screens are used with this film to eliminate certain undesirable light rays and thus increase the ability of the film to record the details desired. These screens are in the form of thin gelatin

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sheets and are inserted back of the front element of the lens. Several grades are available for use to compensate various atmospheric conditions.

The camera is provided with a suspension mechanism designed to reduce vibration and to make possible the leveling and orientation of the camera to obtain the most advantageous position for aerial mapping. This is accomplished by hanging the camera in a gimbal mount, which is equipped with rollers traveling on a circular track, and providing the entire apparatus with brackets and shock-absorbing cushions by which it may be attached to the fuselage of the airplane. These adjustments are necessary, for it is essential that the camera be placed in a predetermined position with respect to ground objects, with the axis of the B lens in an approximately vertical position. The azimuthal adjustment is important, as it is generally necessary to rotate the camera a few degrees in order to compensate for any wind effect on the airplane or to improve the angles of intersection, so that a more strongly adjusted map may be produced.

TRANSFORMER

The three oblique photographs made by a T–2 camera can not readily be used in topographic mapping until they have been reprojected into the plane of the B photograph. A special apparatus, which is both a camera and a printer but is usually called a transformer, shown in Plate 27, is used for this purpose. The spools on which the negative film is carried are shown on the end adjacent to the light source, and on the opposite end of the transformer is the suction back used to hold the photographic paper in the image plane of the lens. A motor and vacuum pump provide the necessary suction. The lens used in this transformer is of the wide-angle type, with a maximum stop opening of f/18 and a focal length of about 7.5 inches. It is set in the interior of the transformer in a partition that divides the negative from the image end. The angles made by the negative and image planes in this transformer are unusual but are fixed by the focal length of the lenses used in the aerial camera and in the transformer and by the dihedral angle between the oblique and horizontal focal planes in the aerial camera. On account of this complex relation it is necessary to construct a transformer for use with each multiple-lens camera.

STEREOSCOPE

The interpretation of aerial photographs is much easier when overlapping prints are examined through a stereoscope, for this instrument has the peculiar property of causing the photographic image to be seen in three dimensions. The third dimension, that of relief, is so strongly emphasized that differences of elevation as small as 50 feet can ordinarily be detected without magnification of the image, and with a special magnifying stereoscope very small differences can be seen and measured. The unusually strong stereoscopic effect obtained when aerial photographs are viewed through a stereoscope is due to the fact that the distance between the eyes (the "eye base") is increased in effect from a few inches to several thousand feet, as the observer sees the photographs as the terrain would appear to one whose eyes were separated by the distance between the exposure points of the two photographs. The magnification of the image by suitable lenses will increase this effect.

Stereoscopes of many different types are constructed, some being intended for use with glass negatives and transmitted light and others for use with photographic prints and reflected light. The high-powered instruments usually have very small fields; those of low power have larger fields. The Geological Survey has several stereoscopes using low magnifications, but by far the most useful is a simple mirror stereoscope of the Pellin type, which is not equipped with lenses for the magnification of the image. The Pellin stereoscope has four mirrors adjustably mounted on a bar and suitable standard in such a manner that by looking downward into two small mirrors the photographs can be seen by reflection in two larger mirrors. It has a large field of view, and the size of the image reaching either eye can be easily and quickly varied a small amount by a simple adjustment of the mirrors. The large field permits a better interpretation of the relief than can be obtained if only a small area appears in the field, and the variable magnification is helpful in the examination of those T–2 photographs that can not be viewed stereoscopically in the outer parts owing to differences in scale introduced by rolling of the airplane. Two such prints can often be brought to the same scale and a satisfactory stereoscopic view obtained by sliding the large reflecting mirrors along the bar on which they are mounted until a position is found that permits the merging of the two images.

Several forms of stereoscopic instruments have been designed for the purpose of making very exact measurements from aerial photographs that enable the topographer to complete the mapping of an area without field work other than the usual control surveys. This interesting phase of the subject of photogrammetery has not yet been undertaken by the Geological Survey.

PHOTOGRAPHIC OPTICS

An elementary knowledge of the formation of an image by lenses is essential to a thorough understanding of photographs used in mapping, and this applies to photographs taken in the air or from the ground. A short study of this subject will also explain the underlying principle of the stadia and of all other devices in which angular or linear measurements of an image in the plane of the reticle are made. Neither the use of the panoramic mapping camera nor the theory of the transformer can be clearly understood without a knowledge of this principle.

OPTICAL DEFINITIONS AND FORMULAS

The optical axis of a lens is the path of a ray that will pass through the lens without deflection. In a well-centered lens the axis passes through the centers of curvature of the different lens surfaces.

If rays from a very distant object (such as the sun) are allowed to pass through a lens, the image will be formed in a plane called the secondary focal plane, or image plane. The primary focal plane can be found by reversing the lens and allowing the image to form on the opposite side of the lens. The intersections of the axis with these focal planes are the focal points of the lens and will be referred to as the principal points.

The two nodal planes are perpendicular to the axis and pass through the nodal points of the lens, which are designated the nodal point of incidence and the nodal point of emergence. One of the most interesting properties of the nodal points is that a ray entering the lens from any direction toward the nodal point of incidence will leave the lens parallel to its original direction but as if it had come from the nodal point of emergence. The location of these points can be found graphically by extending the incident and refracted ray to intersection with the optical axis, as shown in Figure 14, in which the nodal points of incidence and emergence for a double convex lens are designated by the letters N and N', respectively. A study of this figure will show that regardless of the direction from which the ray approaches the nodal point of incidence it can be considered as leaving the lens from the other nodal point and parallel to its original direction. This property is utilized in measuring the focal length of a lens and in the construction of panoramic cameras, for it can be seen that a lens can be rotated about an axis passing through the nodal point of emergence without causing a movement of the image on a screen. The nodal points may fall outside as well as inside the lens, their separation and position being fixed by the type of lens under consideration.

The object and image planes are also perpendicular to the lens axis and as their names suggest are the planes in which are found the object and its image. These planes are conjugate and have a fixed relation to each other that must be known in order to determine the scale of the image.

The equivalent focal length of a lens is the distance from the nodal plane to the image plane. The back focus is the distance between the rear surface of the lens and the image plane.

The focal length of a lens and the position of its nodal points can be readily determined on an optical bench and should always be known for all lenses used in mapping cameras. With a knowledge of these constants it is possible to determine the position and size of an image, either graphically or by computation. The graphic solution commonly used is as follows: A ray from A (fig. 15) parallel to the axis can be considered as passing through the lens as

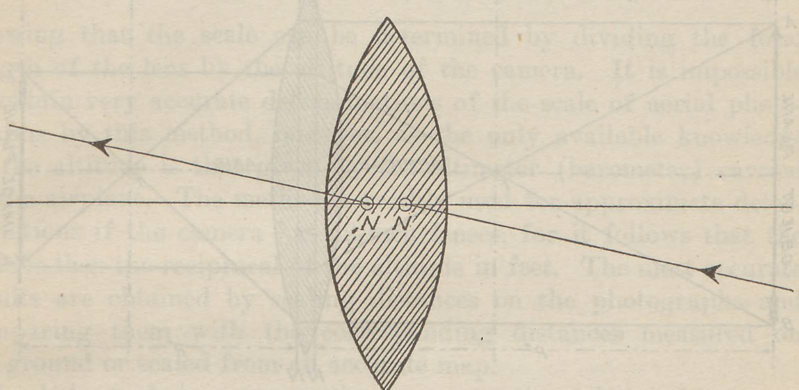


FIGURE 14.—Nodal points of a double convex lens

far as the nodal plane of emergence and there being refracted so that it passes in a straight line through the rear focal point. Another ray from A can be considered to travel straight through the front focal point as far as the nodal plane of incidence and from this point be parallel to the axis of the lens. The intersection of these two rays (a) is the location of the image of point A. In a similar manner the location of the image of point B can be found. The path of the actual rays through the lens is quite unlike this, although the location of the image is accurately given by this graphic method.

The primary and secondary focal points are shown in the same figure at F and F', respectively; the distances from these points to the object and image planes are denoted by x and x' and the focal length is f. The distances $x+f$ and $x'+f$ are designated p and p', respectively. With this notation it is evident that

$$\frac{\text{size of object }(AB)}{\text{size of image }(ab)}=\frac{p-f}{f}=\frac{f}{p'-f} \qquad (1)$$

By equating the last terms and simplifying the expression it can be reduced to the easily remembered relation

$$\frac{1}{p}+\frac{1}{p'}=\frac{1}{f} \qquad (2)$$

It is also possible to derive from the figures the relations

$$\frac{\text{image size}}{\text{object size}}=\frac{p'}{p} \qquad (3)$$

$$f^2=xx' \qquad (4)$$

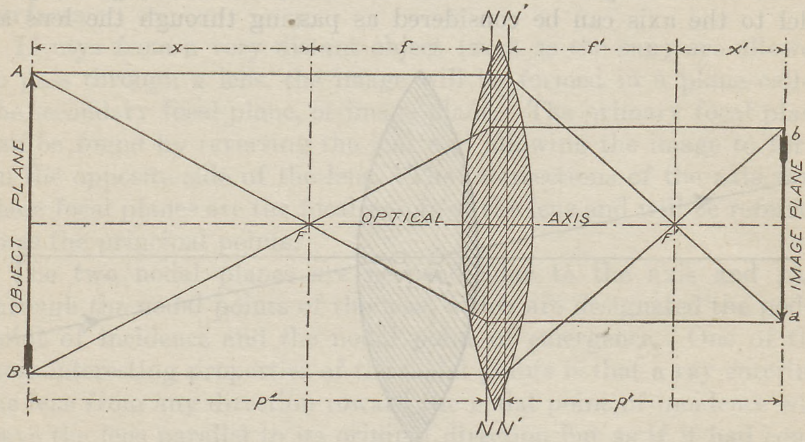


FIGURE 15.—Conjugate focal planes

As the scale of a map or aerial photograph is expressed as the ratio of size of drawing to size of original, equation 3 can be rewritten as

$$\frac{1}{r}=\frac{\text{image size}}{\text{object size}}=\frac{p'}{p} \qquad (5)$$

where $\frac{1}{r}$ denotes the scale.

The expression $xx'=f^2$ is easily derived from equation 1 and is the condition that must be fulfilled in order to obtain a sharply focused image.

SCALE OF AN AERIAL PHOTOGRAPH

Equation 5 shows that the scale of an aerial photograph can be found from the ratio of distances to image and object planes when the measurements are made from the lens or from the ratio of the length of a line measured on a photograph to the length of the corresponding line on the ground. The ideal condition of a horizontal plate and a horizontal ground surface must be assumed.

It is evident that under the conditions in which aerial photographs are made the distance from the camera lens to the object plane is the altitude (H) of the camera and corresponds to the distance p in equation 5 and Figure 15. The substitution of widely separated values of H (or p) in equation 5 will show that for all altitudes at which aerial mapping is done p' is practically equal to f, the focal length. This equation may therefore be written

$$\frac{1}{r}=\frac{f}{H} \qquad (6)$$

showing that the scale can be determined by dividing the focal length of the lens by the altitude of the camera. It is impossible to obtain very accurate determinations of the scale of aerial photographs by this method, however, as the only available knowledge of the altitude is that given by the altimeter (barometer) carried in the airplane. The method is readily used for approximate determinations if the camera has 12-inch lenses, for it follows that the scale is then the reciprocal of the altitude in feet. The most accurate results are obtained by scaling distances on the photographs and comparing them with the corresponding distances measured on the ground or scaled from an accurate map.

A photograph is a perspective representation of the objects appearing in it, and consequently has no uniform scale throughout unless the objects photographed are all in one plane that is parallel to the focal plane of the camera. This condition is so difficult of accomplishment in an aerial photograph that it is never fulfilled exactly, although good photographic flying over level areas will furnish aerial photographs that are nearly uniform throughout in the matter of scale. Uniformity of scale can not be obtained if differences of elevation exist within the area photographed, or if the camera axis is inclined, however slightly, to the vertical, and consequently the scale quoted for an aerial photograph must be considered only an approximation. It is evident that the top of a plateau or mesa will photograph to a larger scale than the valley land at its base, and for the same reason all photographs of any but very level land can not have a given scale throughout.

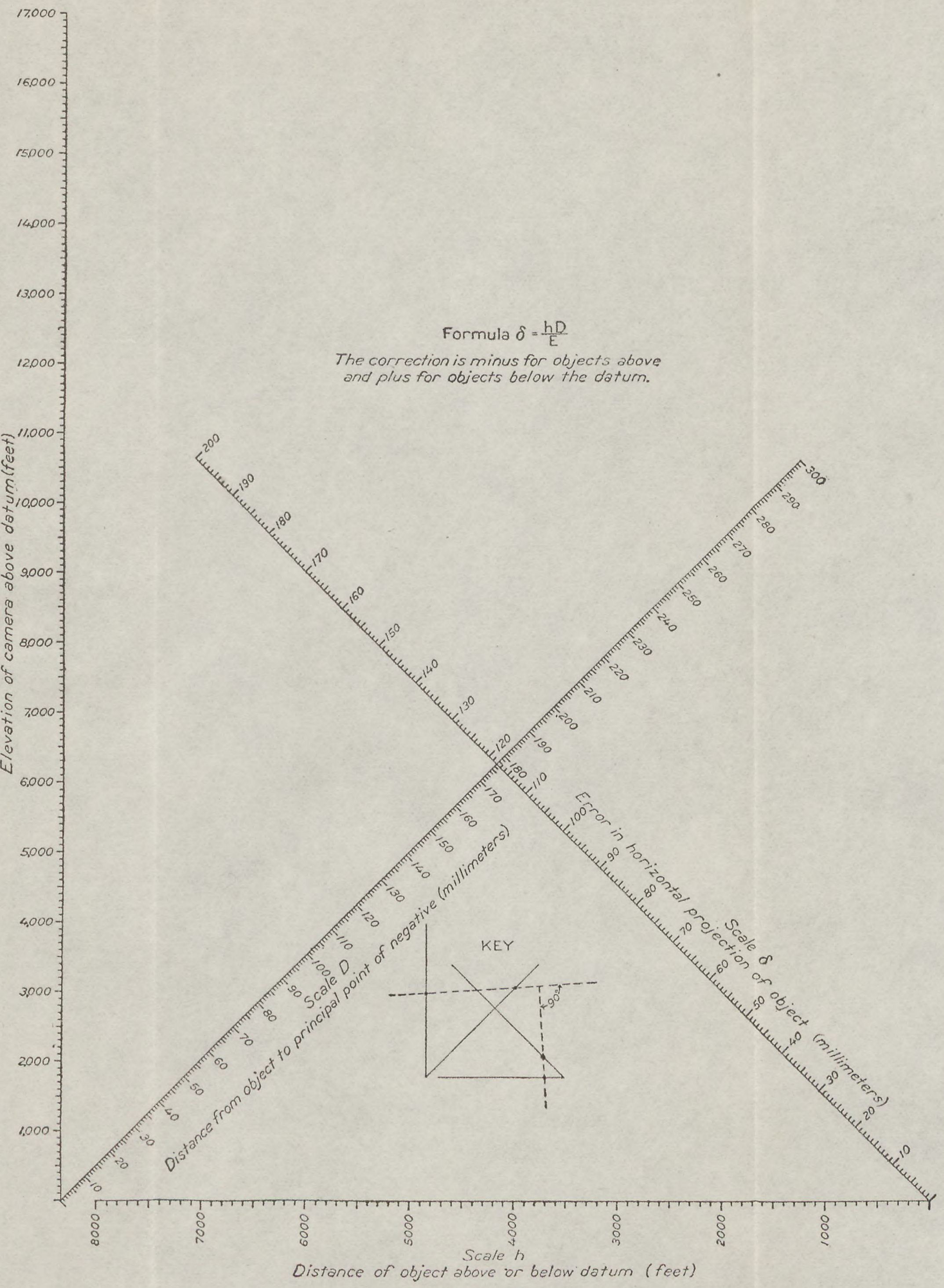
This variation in scale and other displacements that exist in the aerial photographs make it impossible to enlarge or reduce them successfully to any desired scale.

SOME DISTORTIONS OF A PHOTOGRAPHIC IMAGE

Two types of aerial photographs are employed for mapping, differing only in the position of the camera axis at the moment of exposure. Photographs made with the axis within a few degrees of the vertical are called "verticals;" all others are called "obliques." As the condition of exact verticality of the lens axis is difficult to fulfill, the term "verticals" is now used to designate photographs that are made with the lens axis in an approximately vertical position. Photographs obtained while every effort is being made by the pilot and observer to maintain the camera axis truly vertical are the so-called "verticals"; those made with the axis intentionally inclined are the "obliques."

A truly vertical photograph of a horizontal ground surface—that is, a photograph taken when the photographic plate is exactly horizontal—is a reduced copy of the original and is, in a sense, a map, as it is a reduced horizontal projection of the original. If the camera axis is not exactly vertical or the terrain photographed is not horizontal this condition is not fulfilled, and a photographic image is obtained that shows the ground features in improper relation. Fortunately these displacements follow definite mathematical and geometrical rules and can be corrected if the factors causing the displacements are known.

If angles between points on a photographic plate are measured at its center it can be proved that they equal the corresponding horizontal angles that would be measured by a transit, providing that the photographic plate was horizontal and vertically above the transit station when the photograph was made. If *A*, *B*, *C*, Figure 16, represent three points on a horizontal ground surface subtending the angles *ANB* and *BNC* at the point *N*, which is vertically below the aerial camera and is therefore called the nadir point, and *a*, *b*, *c*, represent the corresponding images of these points on the horizontal plate, it is evident that the angles *appb* and *bppc* on the plate will equal the angles *ANB* and *BNC* on the ground. This equality of corresponding angles also exists whatever may be the elevation of points *A*, *B*, and *C*, for although the points may be displaced on the plate by their position above or below the datum plane, these displacements are radial and do not affect the size of the subtended angles. That this is true can be seen by reference to Figure 17. In this figure, *A* is the high point, *A′* its projected position in the datum plane, *ppN* a vertical line passing through the lens and perpendicular to both the photographic plate and the datum plane; *a′* is the image of point *A′* and *a* the image of point *A*. The figure shows that the difference of elevation *AA′* causes the image point to



DISPLACEMENT CHART

be displaced on the plate from *a′* to *a*, and as *A* is vertically above *A′*, the triangles *AOA′* and *aOa′* are in a vertical plane which is perpendicular to the plate and which contains the line *ppN*. This being so, *a* and *a′* must be on a radial line passing through the plate center *pp*, and thus the displacement due to the difference of eleva-

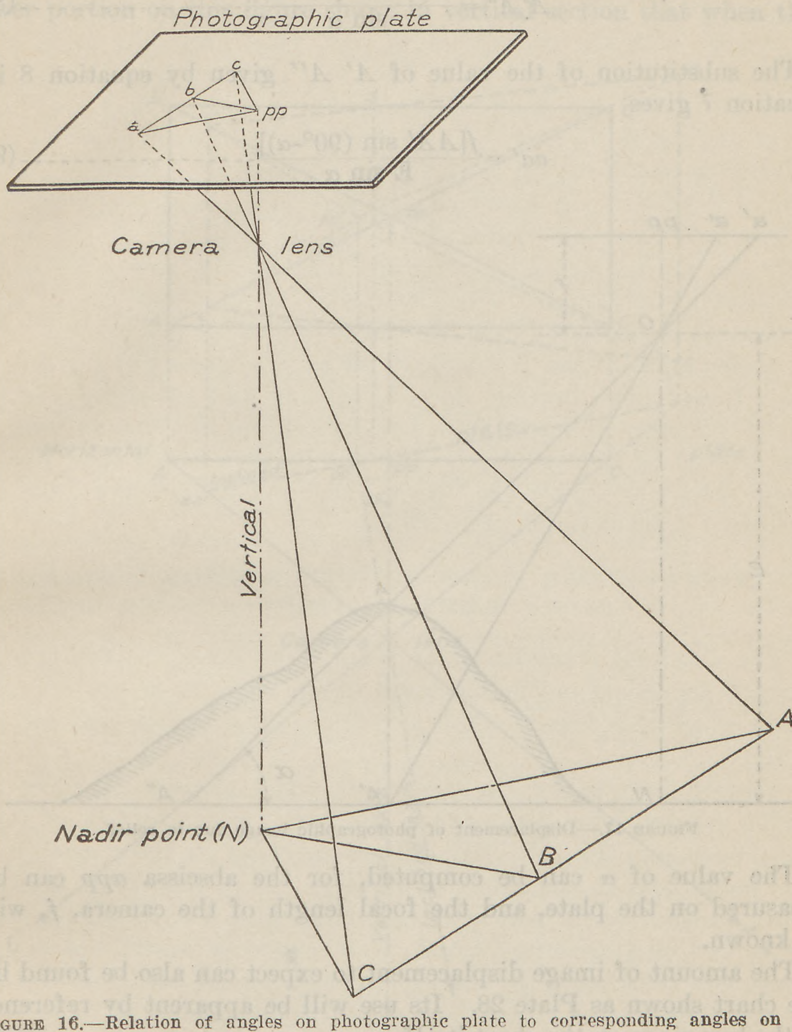


FIGURE 16.—Relation of angles on photographic plate to corresponding angles on the ground

tion can not affect the value of angles measured at the center of the photograph. The amount of image displacement due to the elevation of an object can be easily found from Figure 17. Let the angle $AA''A' = \alpha$, which is identical in value with the angle *ppaO*, as they are alternate angles. The altitude of the camera lens is *E*, and its focal length, ppO, is f. The following equations are easily derived from this figure:

$$\frac{aa'}{A'A''}=\frac{f}{E} \quad (7)$$

$$A'A''=\frac{AA' \sin (90°-\alpha)}{\sin \alpha} \quad (8)$$

The substitution of the value of $A'\ A''$ given by equation 8 in equation 7 gives

$$aa'=\frac{f[AA' \sin (90°-\alpha)]}{E \sin \alpha} \quad (9)$$

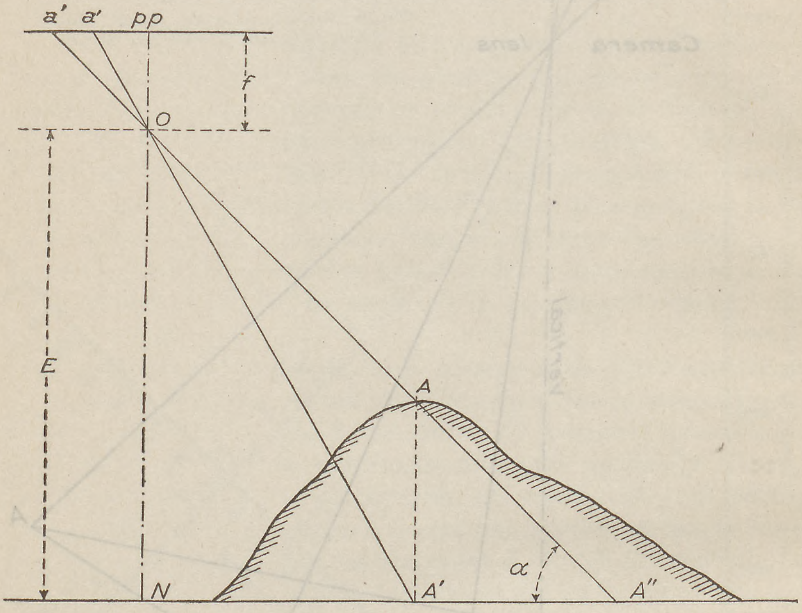


FIGURE 17.—Displacement of photographic image due to relief

The value of α can be computed, for the abscissa app can be measured on the plate, and the focal length of the camera, f, will be known.

The amount of image displacement to expect can also be found by the chart shown as Plate 28. Its use will be apparent by reference to the key given on the chart itself.

Any inclination of the camera axis will distort the angles on the plate and render them useless for all purposes that demand exactitude in this regard. The angles are sufficiently accurate for small-scale mapping, however, if the tilt of the camera is not more than is ordinarily encountered in good photographic flying. A skilled pilot may be expected to keep his airplane within 3° of the horizontal, and as long as this angle is not exceeded no difficulty due to erroneous values of the central angles will be encountered in the use of the photographs. The effect of a tilt at right angles to the direction of flight is shown in Figure 18, in which the tilt is assumed as the large amount of 10° in order to render the effect more apparent. The lower portion on this figure shows in vertical section that when the

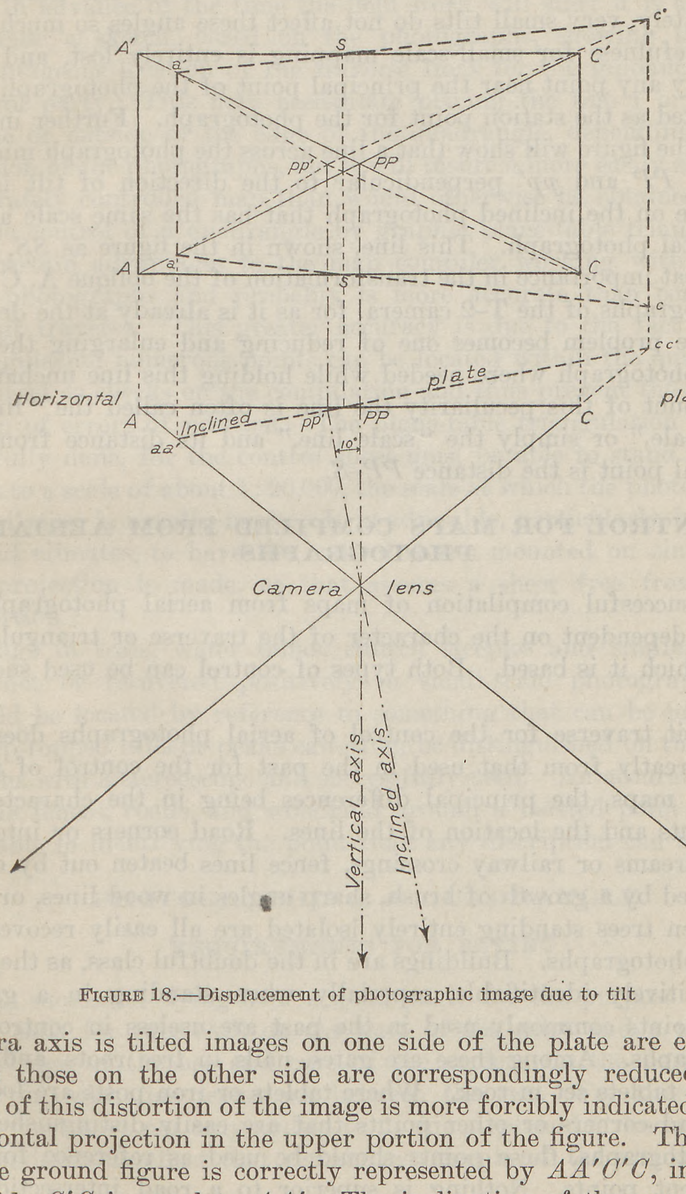


FIGURE 18.—Displacement of photographic image due to tilt

camera axis is tilted images on one side of the plate are enlarged while those on the other side are correspondingly reduced. The effect of this distortion of the image is more forcibly indicated by the horizontal projection in the upper portion of the figure. The shape of the ground figure is correctly represented by $AA'C'C$, in which the side $C'C$ is equal to AA'. The inclination of the camera distorts the figure, however, and *aa′c′c* results, in which the side *aa′* is shorter than the side *c′c*, obviously an incorrect representation. The figure also shows that the tilt of the axis causes the principal point of the plate to move from *PP* to *pp′* and therefore distorts all angles measured from this point. This change in the value of the angles can be seen when the dotted lines radiating from *pp′* are compared with the corresponding solid lines from the point *PP*. Fortunately, very small tilts do not affect these angles so much that their usefulness for small-scale mapping is entirely lost, and consequently any point near the principal point of the photograph may be selected as the station point for the photograph. Further inspection of the figure will show that a line across the photograph midway between *PP* and *pp′* perpendicular to the direction of tilt is the only line on the inclined photograph that has the same scale as the horizontal photograph. This line, shown in the figure as *SS*, is of very great importance in the transformation of the oblique A, C, and D photographs of the T–2 camera, for as it is already at the desired scale the problem becomes one of reducing and enlarging the rest of the photograph where needed while holding this line unchanged. On account of this peculiarity the line is often called the "line of equal scale," or simply the "scale line," and its distance from the principal point is the distance *PP–S*.

CONTROL FOR MAPS COMPILED FROM AERIAL PHOTOGRAPHS

The succesful compilation of maps from aerial photographs is largely dependent on the character of the traverse or triangulation upon which it is based. Both types of control can be used successfully.

Transit traverse for the control of aerial photographs does not differ greatly from that used in the past for the control of topographic maps, the principal differences being in the character of the points and the location of the lines. Road corners or intersections, streams or railway crossings, fence lines beaten out by cattle or defined by a growth of brush, sharp angles in wood lines, or lone evergreen trees standing entirely isolated are all easily recoverable on the photographs. Buildings are in the doubtful class, as they are not positively identifiable, especially when standing in a group. Many points commonly used in the past are useless in controlling photographs. Among these are gates, nails in tree roots, and iron posts or tablets set in rock. Where tablets or iron posts are located near road corners or other points that are easily distinguished on the photographs, these points should be used as reference for the permanent points. Nothing is superior to a road intersection in sectionized country.

Single-lens photographs can usually be well controlled by a transit-traverse line around and across the center of the quadrangle, but for multiple-lens photographs the best control is obtained only when points are so located that they will be found on the center and on each oblique print both at the beginning and end of each flight, and this combination is often not attained when the traverse line is run before the photographs are made. When the flying has been done well in advance of the time the field work will start it is advisable to make a sketch, based on the photographs, showing the most advantageous location of the traverse lines for the guidance of the control party. This may necessitate placing the line 1 or 2 miles inside or outside of the edge of the quadrangle, depending on the location of the photographs, but it will insure a more easily and more accurately controlled map than would otherwise be obtained.

The control of a quadrangle by graphic plane-table triangulation has certain advantages to the map compiler working with T–1 or T–2 photographs and probably is more accurate than control by transit traverse. This greater accuracy is due to the fact that by triangulation numerous points can be located within the quadrangle and used as checks on the compilation and thus prevent the accumulation of errors of position. The plane-table triangulation must be carefully done, for the control sheet must be able to stand enlargement to a scale of about 1:20,000, the scale at which the photographic compilation is usually made. It is advisable, particularly in wet or humid climates, to have the control sheets mounted on zinc before the projection is made, as that assures a sheet free from paper distortion.

Flags in trees, water tanks, church steeples and similar points can not be recovered positively in small-scale photographs and should be located by reference to something that can be identified. Sharp-topped hills or peaks can often be distinguished on the photographs with a stereoscope and successfully used. An accurate sketch of the fences, roads, and woodland around a located point is more valuable in identifying the point than any discription can be.

PHOTOGRAPHING A QUADRANGLE

REQUIREMENTS FOR FLYING

The successful flying over a quadrangle for the purpose of mapping calls for rare skill on the part of the pilot and a thorough knowledge of the use and care of the camera on the part of the observer, with fine teamwork between the two. For this work a pilot must have not only ability to fly his airplane but knowledge of the undesirable effect that certain movements of the airplane have upon the photographs and the proper procedure to take to avoid them. There is nothing more discouraging to one who must compile the base maps from aerial photographs than the receipt of a shipment of photographs that immediately display the pilot's unfamiliarity with photographic flying or his carelessness. Inability to keep the airplane on an even keel, "banking" on the slight changes in direction that are made in attempting to keep on a predetermined course, and continuous changes in altitude are all very clearly indicated on the photographs and with an exactness far beyond that of any indicating instruments that may be carried in the airplane. The speed and accuracy with which a base map may be compiled being largely influenced by these factors, it is essential that the pilot should clearly realize their effect and fly his airplane in such a manner that it will be minimized. An exact knowledge of his position at all times and ability to recognize landmarks and fly by them can be acquired by practice and are essential to the photographic pilot.

In sectionized country photographic flying is best done in the north or south direction. This is specially important for work done with the single-lens camera, as the photographs can be worked up with greater ease and more valuable comparisons can be made with section-line measurements than is possible when the flights are directed east or west. For flights along stream valleys, where only the course of the stream is to be mapped, or for flights over country that has not been sectionized, courses can be chosen that are most convenient to the pilot, and with regard to the layout of control, existing or proposed, although in flying along a stream the changes in direction should be made with as little banking of the plane as possible.

The question of the correct exposure to be given to an aerial photograph is fixed not so much by the lighting of the subject as it is by the exposure necessary to "stop" the movement of the image on the film. A photographic airplane flying at 80 miles an hour is moving at a rate of 117 feet a second. When flying at 12,000 feet with a camera having a 12-inch lens the image of a given point on the ground will move a distance of about 0.12 inch on the plate in 1 second. To make a sharp picture it is essential that the shutter exposure be short enough to prevent any blurring of the image on account of this movement, and it has been found that $\frac{1}{150}$ of a second will easily accomplish this end and will ordinarily prevent any indistinctness due to vibrations that are transmitted to the camera through its shock-absorbing suspension. In order that the aerial photographic work may be carried on at any time during reasonably clear weather, hypersensitized panchromatic film is used, and the cameras are equipped with lenses having maximum stop openings of f/4.5 and light filters of various degrees of absorption. American aerial cameras are commonly equipped with "between the lens" shutters, for these, although not so efficient as the focal-plane shutters, do not cause distortion of the image by their method of operation. This disadvantage of the focal-plane shutter is more theoretical than real for small-scale mapping, however, for the flying is done at so great an altitude that the movement of the image is slow and the resulting distortion consequently very small.

To compute the altitude at which he should fly in order that the photographs may be made at a predetermined scale, it is essential that the pilot should know the general elevation of the country over which the work will be done and the exact focal length of the camera lens. The fact that a camera has, for example, a 12-inch or a 6-inch lens is not sufficient to fix more than approximately the altitude at which the photography should be undertaken. The exact value of the focal length of every camera lens used for mapping should be obtainable by the pilot or observer from the records of his office. The altitude at which the flying should be done in order to obtain the desired scale can be determined by the relation

$$\text{Altitude} = \frac{f}{r}$$

in which f is the focal length in feet and r the scale expressed as a fraction.

In hilly country it is impossible to have the photographs at a constant scale throughout, but by selecting the mean elevation of the country as a datum plane for determining the scale, the variations in this respect will be at a minimum.

After the altitude at which the flying should be done has been determined it is the pilot's duty to find and maintain this altitude while the photographs are being made. The accuracy of the altimeter will determine how nearly the desired altitude can be approached, and its readiness in responding quickly to small changes of altitude will determine how closely the altitude can be maintained. Although every change in level of the airplane is indicated in the photographs as a change in scale, this difficulty is probably the least troublesome of all with which the map compiler must contend and apparently is the feature in which photographic pilots approach nearest to perfection. The small-scale changes that are always to be expected in aerial photographs do not increase the difficulty of compilation or introduce errors of any kind in the resulting map when T–1 or T–2 photographs are used, for all compilation with these photographs is based on the radial-line method, which is independent of the scale of the prints. Differences in scale on single-lens photographs, however, seriously affect the compilation, as there is no economical way of reducing them to a common datum. It is possible to eliminate such differences from single-lens photographs having a scale of 1:10,000, or less, by using the intersection method, providing that large end and side overlaps were obtained by the pilot and that numerous well-determined control points exist upon which to base the compilation. But this is very expensive, and for several other reasons this method can not economically be used with single-lens photographs in small-scale map compilation. The area covered by a single-lens photograph is relatively small (see table on p. 399), and consequently it is necessary to space the control points closely in order to get at least three points on each photograph at the beginning of each flight. Where this distribution of points is available and the overlaps are sufficiently large the graphic control net can be extended with accuracy for several miles, and this distance would be greatly increased if it were possible to work from the negatives and have the advantage of using the proper stereoscopic instruments. For the sake of accuracy and ease of compilation it is well to have another line of control across the center of the area to be mapped that will serve as a check on the accuracy of the graphic control and as a basis for a new start. On a 15-minute quadrangle this will call for three lines of control across the area with computed points at intervals of not more than half a mile and preferably closer. Another serious difficulty is that of the time demanded to work up a satisfactory strong control net with the large number of photographs that must be handled. Still another lies in the skill needed to maintain accurate orientation of the prints with the short lines available. This difficulty arises from the fact that the longest line that can be used for orientation is equal to the semidiagonal of the photographic print. This distance is about 5 inches, whereas the centers of adjacent photographs will ordinarily be separated by 3 inches. This gives a ratio of 5 to 3, which is too low to give the accuracy that can be obtained from tri-lens photographs having a ratio of 5 to 1.

Areas covered by aerial-mapping cameras

Single-lens camera, 18 by 24 centimeter (7 by 9 inches net), 12-inch focus					Three-lens camera (T-1), 6.4-inch focus				
Altitude (feet)	Scale	Major axis (miles)	Minor axis (miles)	Area (square miles)	Altitude (feet)	Scale	Major axis (miles)	Minor axis (miles)	Area (square miles)
9,000	1: 9,000	1.278	0.994	1.270	7,000	1:13,125	3.977	1.139	5.41
9,250	1: 9,250	1.314	1.022	1.343	7,250	1:13,594	4.119	1.180	5.80
9,500	1: 9,500	1.349	1.049	1.415	7,500	1:14,062	4.261	1.221	6.21
9,750	1: 9,750	1.385	1.077	1.492	7,750	1:14,531	4.403	1.261	6.63
10,000	1:10,000	1.420	1.105	1.569	8,000	1:15,000	4.545	1.302	7.06
10,250	1:10,250	1.456	1.132	1.648	8,250	1:15,469	4.688	1.343	7.51
10,500	1:10,500	1.491	1.160	1.730	8,500	1:15,937	4.829	1.383	7.97
10,750	1:10,750	1.527	1.188	1.814	8,750	1:16,406	4.972	1.424	8.45
11,000	1:11,000	1.562	1.215	1.898	9,000	1:16,875	5.114	1.465	8.94
11,250	1:11,250	1.598	1.243	1.986	9,250	1:17,344	5.256	1.506	9.44
11,500	1:11,500	1.633	1.270	2.074	9,500	1:17,812	5.398	1.546	9.96
11,750	1:11,750	1.669	1.298	2.166	9,750	1:18,281	5.540	1.587	10.49
12,000	1:12,000	1.705	1.326	2.261	10,000	1:18,750	5.682	1.628	11.06
12,250	1:12,250	1.740	1.353	2.354	10,250	1:19,219	5.824	1.668	11.59
12,500	1:12,500	1.776	1.381	2.453	10,500	1:19,687	5.966	1.709	12.16
12,750	1:12,750	1.811	1.409	2.552	10,750	1:20,156	6.108	1.750	12.75
13,000	1:13,000	1.847	1.436	2.652	11,000	1:20,625	6.250	1.790	13.35
13,250	1:13,250	1.882	1.464	2.755	11,250	1:21,094	6.392	1.831	13.97
13,500	1:13,500	1.918	1.491	2.860	11,500	1:21,562	6.534	1.872	14.59
13,750	1:13,750	1.953	1.519	2.967	11,750	1:22,031	6.676	1.912	15.23
14,000	1:14,000	1.989	1.547	3.077	12,000	1:22,500	6.818	1.953	15.89
14,250	1:14,250	2.024	1.574	3.186	12,250	1:22,969	6.960	1.994	16.56
14,500	1:14,500	2.060	1.602	3.300	12,500	1:23,437	7.102	2.034	17.24
14,750	1:14,750	2.095	1.630	3.415	12,750	1:23,906	7.244	2.075	17.94
15,000	1:15,000	2.131	1.657	3.531	13,000	1:24,375	7.386	2.116	18.65
15,250	1:15,250	2.166	1.685	3.650	13,250	1:24,844	7.528	2.157	19.37
15,500	1:15,500	2.202	1.712	3.770	13,500	1:25,312	7.670	2.197	20.11
15,750	1:15,750	2.237	1.740	3.892	13,750	1:25,781	7.812	2.238	20.86
16,000	1:16,000	2.273	1.768	4.019	14,000	1:26,250	7.955	2.279	21.63
16,250	1:16,250	2.308	1.795	4.143	14,250	1:26,719	8.097	2.319	22.41
16,500	1:16,500	2.344	1.823	4.273	14,500	1:27,187	8.239	2.360	23.20
16,750	1:16,750	2.379	1.850	4.401	14,750	1:27,656	8.381	2.401	24.00
17,000	1:17,000	2.415	1.878	4.535	15,000	1:28,125	8.523	2.441	24.83
17,250	1:17,250	2.450	1.906	4.670	15,250	1:28,594	8.665	2.482	25.66
17,500	1:17,500	2.486	1.933	4.805	15,500	1:29,062	8.807	2.523	26.51
17,750	1:17,750	2.521	1.961	4.944	15,750	1:29,531	8.949	2.563	27.37
18,000	1:18,000	2.557	1.989	5.086	16,000	1:30,000	9.091	2.604	28.25

CHOICE OF SCALES

The scale that should be chosen depends largely on the use for which the photographs are intended. The single-lens type of photograph is usually needed in regions where there is a great concentration of culture, as in cities, and where there is need for extreme sharpness of image. It has been found that a scale of 1:12,000 is sufficiently large to show all the detail that can be included on the map, and on this scale it is possible to cover a sufficient area at each exposure without flying at extreme altitudes. The multiple-lens photographs allow a great variation of scale owing to the short focal length of the lens used with this type of camera. Scales as small as 1:31,680 can be obtained with this camera without requiring the pilot to fly at extraordinary heights. A scale as small as this is advantageous, inasmuch as with it the quadrangle is covered by fewer photographs and less ground control is needed. Experience has indicated, however, that larger scales will serve the topographer's need better, as it is difficult to distinguish buildings and other small objects on a scale of 1:31,680. A scale of 1:20,000 or slightly smaller seems very satisfactory for the compilation of maps for publication on a scale of 1:62,500, as all necessary detail can be distinguished easily on the photographs, and a 15-minute quadrangle can still be covered by three flights of the airplane. With this scale, the sheet on which the base map is drafted is small enough to be easily handled, but that is hardly true with a scale much larger.

OVERLAPS AND "CRABBING" OF PHOTOGRAPHS

A large overlap of the photographs in the direction of flight is absolutely essential to map compilation by the radial-line method, for every point must appear on at least three consecutive prints of a flight in order to make this method operative. This can be accomplished only by so timing the exposure that the overlap shall never be less than about 60 per cent. An overlap of less than 50 per cent is equivalent to a shutter failure so far as the compilation is concerned, for it halts the progress of the work just as effectively as a missing photograph. A lateral overlap is also necessary, in order that adjacent flights may completely cover the area to be photographed, without leaving a strip of unphotographed country between them. This lateral overlap should preferably be about 30 per cent, which effectively ties the two flights together and strengthens the entire net of graphic control. Smaller overlaps than this have the disadvantage of giving weak ties between the flights and should therefore be avoided. The size of the angles of intersection between flights can be somewhat increased by rotating the camera in its mount so that it makes an angle of 10° to 15° with the direction of flight. This procedure is particularly valuable with the T–1 type of photograph but is not so necessary with the T–2 type. Rotation, or "crabbing" of the camera, as it is sometimes called, should not be allowed to exceed 15°, however, as a greater angle renders it extremely difficult to control the photographs by the usual method of running transit control lines.

LABORATORY WORK

The development and fixing of the exposed negatives need not be considered here, as the process does not differ greatly from the usual method of developing panchromatic film or plates and has no bearing on the work of the topographer. The fact that the film is in rolls ranging in length from 100 to 380 feet makes it necessary to develop the film by the tank method and is probably the most unusual feature of this work.

NUMBERING THE NEGATIVES

The films must be numbered in order to identify the prints and to show the order in which the exposures were made. If the job is a large one in which several rolls of film were used the rolls may be numbered separately, and then the consecutive exposures, beginning with 1 for each roll, but consecutive numbering throughout a job is much simpler and more satisfactory to the map compiler. The film from multiple-lens cameras must be numbered in triplicate or quadruplicate, as the A, B, C, and D prints of each exposure must carry the same number. The numbering is done on the margin of the film in a space provided for that purpose adjacent to the shadowgraph showing the camera number. The figures should be put in with black India ink in order that the numbers may print sharply. The single-lens photographs can be numbered in any corner, although it is helpful to have the number always appear in either the northeast or the northwest corner, as this indicates the north direction on the print and is thus a great time saver.

TRANSFORMATION OF OBLIQUE NEGATIVES

The transformation of the oblique A, C, and D negatives and the contact printing of the B negatives is the next step in the preparation of the photographs and is another photographic process in which the topographer is only indirectly interested. The transformation has been so greatly simplified that it is now not much more difficult than contact printing. The careful registration of the negatives with certain index marks in the camera is the only step calling for special care, but this must not be slighted if the A, C, and D prints are to match the B prints properly. Even a slight inaccuracy in the adjustment of a negative in the holder will so distort the print that it will be useless for intersection work.

INDEX MAPS OF AERIAL FLIGHTS

After transforming the negatives the pilot and photographer must prepare an index sketch, or map, on which is shown the approximate location of each strip flown, the direction of flight, and the numbers of the prints at the beginning and end of each strip. This is most easily done by making the index on the best map available, but if no map exists a sketch of the quadrangle should be made and the area covered by each flight indicated. This sketch should give also the date and hour of the flight, as these data are sometimes needed in the compilation.

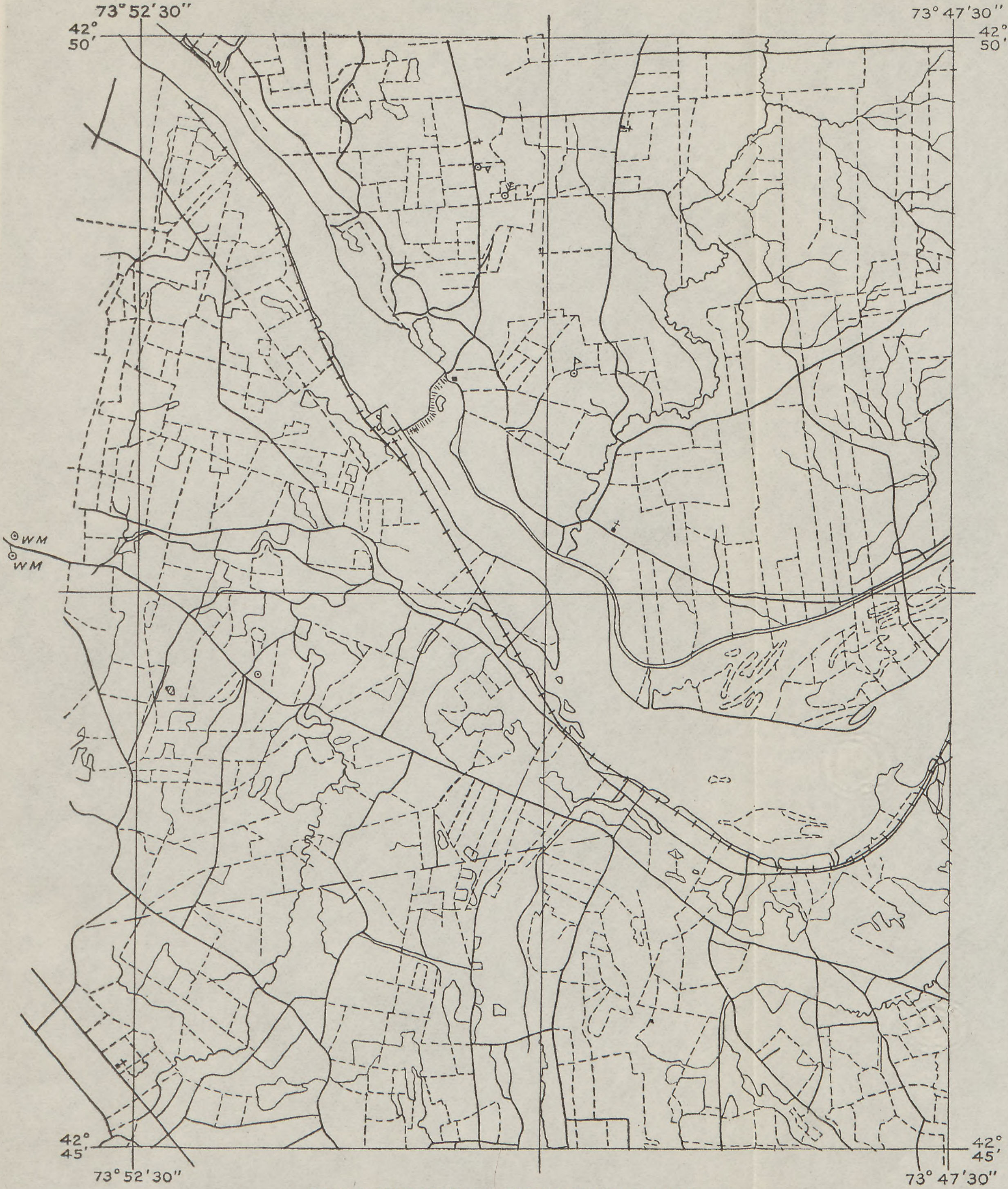
OFFICE PROCEDURE

The unmounted prints and the index map are then sent to the compiling office, where they are mounted and indexed preparatory to the map compilation. The mounting can not be undertaken without a knowledge of the correct alinement and the proper separation of the A, B, C, and D prints. The position that the prints must have in relation to each other when mounted varies slightly for different cameras but is a fixed relation for any one camera. A drawing showing the proper position of the four indexes of each photograph is prepared and used as a copy in the preparation of lithographic prints on heavy paper. The prints are trimmed and " dry mounted " on these sheets, with each axis of the individual photographs superimposed on the corresponding axial line on the mount. Oblique prints that have been correctly transformed and mounted will make a perfect joining with the image on the B print, and the axes of all will fall in the proper positions on the mount. The failure of the assembled composite print to meet these conditions indicates faulty transformation and can be corrected only by a retransformation. As the successful use of multiple-lens photographs depends largely on their mounting, it is important that great care be given to this part of the work.

The assembled composite multiple-lens photographs or the single-lens prints, as the case may be, are numbered consecutively and then filed until they are needed for map compilation. The numbers are entered on cards, which are filed by quadrangles or projects and which contain all pertinent information regarding the aerial photographs and the map compilation to be based on them.

COMPILATION OF MAPS FROM AERIAL PHOTOGRAPHS

Aerial photographs can be assembled for use in compiling a map in various ways. Experience acquired during several years indicates that it is necessary to select that method of compilation which will give the most accurate determination of positions for each individual area. The conditions that largely control this selection are the type of photograph and the relief of the area to be mapped. The lack of horizontality of the photographic film at the moment of exposure affects the usefulness of the photographs severely, but as this condition reflects the skill of the pilot and the flying conditions at the time it can not be accurately determined in advance by the map compiler. However, when the photographs are known to be badly distorted by tilt this fact should be kept in mind in selecting the method of compilation. The methods commonly used by the Geological Survey in compiling maps from aerial photographs are referred



MAP COMPILED FROM AERIAL PHOTOGRAPHS

to as the straight-line method, the section-line method, and the radial-line method. For some uses a picture is more valuable than a map, and a mosaic should be constructed.

STRAIGHT-LINE METHOD

The straight-line method can be most advantageously used to assemble aerial photographs of the single-lens type having large overlaps, in which the distortion of the images due to tilt of the camera or to relief of the terrain is a minimum. To utilize this method it is well to regard the photographs extending from one known control point to another control point as portions of a traverse line. The evenness and regularity with which the photographic work was accomplished and the amount of ground relief will then determine whether it is best to use a single straight line throughout for orientation, or to break the flight up into several smaller sections. For a country of small surface relief it will generally be possible to utilize a single straight line for orientation of the photographs.

The principal point of each photograph should be located approximately by drawing its two diagonals, after which the photographs should be laid out in regular order on a large table and fitted together as accurately as possible by photographic images alone. A straight edge is then placed on the assembled photographic strip and so adjusted that its edge will pass as closely as possible to the principal point of each of the photographs, the fact being kept in mind that a well-selected line should have an equal number of principal points at equal distances to each side. The line indicated by the straight edge should be transferred to the end photograph that is uppermost in the strip of photographs, by carefully drawing a fine sharp line along the straight edge. This line is drawn on only one photograph. The photographs are then taken up from the drafting table in order to extend the straight line onto each photograph in turn. On the straight line drawn on the first photograph and in the region overlapped by the second photograph two points as far apart as possible are selected. These points should be very sharply defined, in order that they can be positively identified on the second photograph. Through these two points so identified on the second photograph a fine sharp line is drawn and produced to each side of the photograph. This process is repeated with the second and third photographs, and so on until such a line has been drawn on each photograph in the strip. There now appears on each photograph a line that is identical in azimuth with the lines on all the other photographs. A straight line is then drawn on any large sheet of paper as a guide, and the first photograph is placed over it, so oriented that the line on the photograph will coincide with the line on the paper.

This photograph should be held in place in any convenient manner, and the second photograph should be similarly adjusted over the guide line and slipped along with the same orientation, until any point on or near this line is exactly above the same point on the first photograph. The process is repeated with the third and succeeding photographs. These photographs are then as accurately joined as is possible by this method and should be permanently fastened together in this position.

It is often impossible to utilize a single straight line from beginning to end of a flight on account of the disposition of the photographs. If the airplane was badly "crabbed" with respect to the line of flight on account of adverse winds, or if the line of flight was irregular, it will be found impossible to select a single straight line that will not depart a considerable distance from the line of principal points. In this event a line should be selected that will fulfill the desired condition for as large a number of adjacent photographs as possible, and one or more additional straight lines should be similarly selected for the remainder of the strip. Usually two lines will be sufficient to control a strip of the length ordinarily occurring between fixed control points.

In any event the entire strip of photographs extending between fixed control points should be laid out and fitted together by photographic images as described above for orientation by a single straight line. The directions of the two or more guide lines can then be determined from inspection of the principal points of the photographs, and the one or more photographs on which an intersection of the guide lines should be located can be selected. The guide lines should then be transferred to the one or more photographs on which bends in the composite guide line occur, making the intersections or bends at the principal points of the photographs. Working in both directions from the photograph on which the first bend occurs the guide lines should be transferred to each photograph in turn as described above for a single guide line. If more than two guide lines are necessary, the transfer of the second guide line should be duplicated, working forward from the first bend and backward from the second, and the best possible adjustment should be made in the final orientation. The angles between adjacent guide lines are obtained from the photographs on which the bends occur. The first angle should be reproduced on the guide sheet and the courses carefully extended. The photographs are then oriented and adjusted as described above for a single guide line except that the work is started at the first bend and carried in both directions. If more than two guide lines are used, the adjustment of the photographs along the second course should be carried to the second bend. If there is an appreciable difference between the projected guide line and the one originally drawn at the second bend the photographs should be readjusted, beginning at the second bend and working backward until the discrepancy disappears. In any event the adjustment of the third course should be commenced at the second bend and carried forward from the original position and direction of the plotted guide line.

The best location of the control points with respect to the guide line and the centers of the photographs will be obtained by intersecting the control points from the principal points of the photographs on which they appear. These intersections are made on the sheet on which the guide line is drawn. Location of the control points by this method is particularly important if these points fall near the edges of the photographs.

The data desired from this strip mosaic, as it is commonly called, can then be reduced to the scale of the map either by pantograph or by photography, the amount of reduction being determined by comparing the map distance between the control points with the distance indicated on the photographs. If the reduction is made photographically, it will be necessary to trace in ink the data desired before reduction. This process gives a narrow strip map showing an area extending between known control points on a scale that very closely approximates the scale of the map that is to be drawn. This strip map is very much like a road traverse by a topographer who has extended his sketching out to a distance of three-quarters of a mile to each side of his plane-table stations, except that no contours are shown. A number of such interlocking strip maps should be considered, in adjusting them to the base map, as so many traverse lines, and they will require the same consideration in adjustment that is given to plane-table traverse. It will be found, however, that the photographic strip maps will have very small discrepancies in scale, probably not over 50 or 100 feet, and they can easily be adjusted to true distances.

In many areas known control points may not be available for determining the mean scale of the photographs, or for fixing the strip in proper position on the compilation sheet. The proper procedure under such conditions can be determined only after a careful study of the material and data available. In general, the photographic strips on which two or more control points occur should be adjusted first. The photographic strips without control will then be dependent on these adjusted strips for position and scale. If the photographs reveal any straight lines, such as roads, railroads, or section or fence lines, passing from one adjusted strip to another, these should be carefully noted, as they are of very great help to the map compiler in fixing the scale and orientation of all the map detail in their vicinity. The intervening strips are compiled by the usual straight-line method, definite points that exist on both the controlled and the uncontrolled strips being used as a basis for determining the scale for the new strip. A single strip can be added on each side of an adjusted strip in this way, and these in turn will serve to adjust other strips. All the skill and judgment possessed by the compiler will be called into use to obtain even a reasonably good adjustment under such conditions, and if the distance between adjusted strips is more than 3 or 4 miles the positions shown on the resultant map will not be of great accuracy. If the area has been covered by the section lines of the public-land system the problem is simple, as explained below.

The straight-line method will fail absolutely or will result in a poor orientation of the photographs if a large overlap between successive photographs is not obtained throughout the flight. The distances measured along the strip map in the direction of flight will be fairly accurate if the country being mapped is flat, but they will not be uniform in scale throughout if it has considerable relief.

SECTION-LINE METHOD

The section-line method will give excellent results with photographs of either the single-lens or multiple-lens type, if it is possible to reconstruct accurately the net of section lines from the notes of the original survey, and if these lines or their corners can be identified on the photographs. Roads or fences known to be on section lines offer the best means of identification on the photographs. If the section lines are not marked on the ground so as to show on the photographs, it will be necessary in advance of the flying to mark the section corners by large white markers, such as white cloth banners or whitewash crosses on the ground or white banners in trees.

With a line of transit traverse extending around the quadrangle and another across the center in an east-west direction it is possible to reconstruct the land net with the accuracy demanded by the usual field-map scales, even if the surveyor's chain used in the original survey was not true in length. In this case a correction is obtained for the particular chain used by the surveyor, by comparing true distances between transit-traverse points with corresponding distances as measured with the chain. For this comparison it is permissible to use scaled distances between carefully plotted transit-traverse points, so that it is possible to make numerous determinations of this correction, both in north-south and in east-west directions. The photographs can then be adjusted to the net of section lines, because known points are available at each section and quarter-section corner, and the desired data can be reduced by the pantograph or by photography and transferred to this net. This method should always be used wherever it is possible to obtain a good adjustment of the public-land net.

It may be found impossible to reconcile the distances given by the photographs with those of the adjusted land lines. This indicates that the adjustment is at fault, either locally or as a whole. It is often possible to obtain a better adjustment by disregarding the notes of the original survey and reconstructing the net wholly from data taken from the photographs. This method is slow and should be undertaken only when absolutely necessary, for it calls for a very close analysis of all the data available to the map compiler. The errors that were bound to creep into the notes of old surveys, because the azimuths of the lines were determined by magnetic compass, are often clearly indicated in aerial photographs by slight bends in the lines that the surveyor intended to be straight. These slight deviations in azimuth can be detected and measured on the photographs with a fair degree of accuracy.

In order to reconstruct the net of section lines from the photographs, it is advisable to lay down the meridional lines first. These lines are more likely to be straight than east-west lines, and they have the great advantage that they can be traced between transit-traverse points on a single set of north-south overlapping photographs. The overlap is very valuable in detecting bends in the section line that is being traced. Should a section line be followed in this way and found to be straight, it can be drawn on the map with confidence, for it is manifestly impossible for a topographer working on a field scale of 1:48,000 to detect deviations that the map compiler can not find on photographs having a scale of 1:12,000. The section corners can be tentatively plotted along such lines by applying the accepted correction to the chained distances as given in the field notes of the original survey. The photographs should then be carefully examined in order to find any east-west lines that are straight between transit-traverse stations. These are more difficult to find than north-south lines, for in general they are bent, many of them are offset on the range lines, and they are difficult to handle because it is necessary to use photographs from many different flights, between which there is not usually a large overlap.

A well-constructed index map is a great help in this work, as it will show the photographs that are adjacent in a lateral direction and enable the map compiler to follow rapidly the section line that he is investigating. As the later overlap is usually very small it is of no help in detecting bends in a line. Fortunately, such bends are generally found at section or quarter-section corners, and a test with a straightedge will determine whether the line is straight through such points. Such east-west lines as are found by this test to be straight throughout are then added to the map, and their intersections with the straight north-south lines previously placed on the map are carefully marked as the most probable locations of these corners. If such located corners do not agree in position with those obtained by applying a correction to the chained distances, the latter should be abandoned. The north-south lines in which bends occur can now be handled more easily. Such lines should be reconstructed on tracing paper to the map scale, the angular value of the bends being obtained from the photographs. These lines when transferred to the map sheet will give other well-located section corners at points where intersections are obtained with lines previously fixed in position. The remaining corners can usually be located by the corrected chained distances, such locations always being checked by the photographs.

When other methods fail to give satisfactory location of corners on east-west lines, they may be fairly well located by data obtained from the photographs, if the line is controlled at both ends by transit-traverse points. This can be done by reconstructing the line on tracing paper and adjusting it between the transit-traverse points on the map. To obtain the most probable azimuth for each section of the east-west line a tracing is made of the north-south lines that have previously been fixed in position on the map, and to this as a base the east-west lines from the photographs are added, the mean azimuth of each section being used as the best value. These north-south lines are numbered in order from west to east. The mean bearing of each east-west line should be used, for it will be found that the azimuths of such lines, 1 mile in length, are not always the same when determined from each end. These mean bearings can be determined graphically, as follows: Place the tracing of the north-south section lines so that the line passing through the fixed control point on the west side is superimposed on the corresponding line on the photograph. Copy the east-west line desired and mark the point where it cuts the north-south section line No. 2. Adjust the tracing in such a manner that line No. 2 is superimposed on its image on the next photograph to the east, and the same east-west line passes through the primary point on line No. 1. Mark the point where line No. 2 is cut by this east-west line. If this point differs from the position obtained previously, use a point midway between them as the true position for this corner. Continue the location of corners across the entire sheet in this manner, until the transit-traverse point on the east side has been located. The section line shown on the tracing can then be transferred to the map.

The adjustment of the details that make up the body of a map compiled from single-lens photographs is not difficult if the lines representing the public-land system have been accurately adjusted. If the amount of detail to be taken from the photographs is not large, it will probably be best to pantograph the strip mosaics on tracing paper and adjust them to the section lines as plotted on the final map sheet. It has been found that better copy is obtained from the pantograph if a steel stylus is substituted for the usual pencil reproducing point. This stylus should have a thin conical point, slightly rounded on the end so that it will not tear the carbon paper over which it will work. The tracing paper on which the reproduction is to be made is fastened to the drawing table in such manner that it is possible to slide a sheet of carbon paper beneath it. The carbon surface should be upward, so that the movement of the steel point over the tracing paper will cause the drawing to be reproduced on its lower surface. The particular advantage of this method of operation is that an extremely fine, even line is obtained and that by using carbon paper of different colors, the drainage, culture, and woodland features can be shown separately, thus making the drawing more legible. Added advantages are that the steel point rarely needs sharpening and the drawing may be transferred to the map sheet readily by rubbing with a burnisher.

It will generally be found that all such pantographed detail will require some adjustment to fit the control scheme, owing to the fact that any photograph may not have a constant scale throughout, as has been explained elsewhere in this chapter. This variation in scale is due to inclination of the photographic plate at the moment of exposure and will generally be exhibited as a contraction in size of image on one side of the line of flight and an enlargement on the other side.

In mapping areas of great detail it may be advisable to ink on the face of the photograph the detail that is to be shown on the map, using a waterproof black ink. The photographic image can then be bleached out, leaving only the inked lines on a white surface. This line drawing can then be reduced photographically to the desired map scale and adjusted to the correct position on the map.

RADIAL-LINE METHOD

The radial-line method of compiling a map from aerial photographs is practically restricted to the multiple-lens type of photograph, because the lines available for orientation on single-lens photographs are not sufficiently long to give the best results. This objection to the use of single-lens photographs largely disappears when the map scale is very large or when great difficulty is encountered in joining the prints by image points owing to displacements caused by the relief of the terrain or tilting of the aerial camera.

On account of the extremely large angle of view utilized in the multiple-lens camera, slight tilts of the airplane or small differences of elevation of the ground surface have very pronounced effects on the photographic image near the outer limits of the angle of view. With ordinary good flying by the pilot, and only small differences of elevation on the ground surface, these effects do not greatly increase the difficulty of utilizing the photographs for small-scale maps. The comparatively large displacements at the edges of the multiple-lens photographs are very valuable in indicating the amount of the displacement due to tilt that exists near the center of the photograph. In the ordinary single-lens photographs the angle of view is so small that it may be impossible to determine whether the photograph is undistorted or not, for the distortions, if present, are not readily apparent to the eye. In using the multiple-lens photographs, however, it can be safely assumed that if known parallel lines or right angles near the edge of the field of view are shown as such in the photograph, then the image near the center must be free from distortion caused by tilting of the airplane, and will have a constant scale throughout.

The principle utilized in the radial-line method of compiling a map from tri-lens photographs is that if from any unknown point the two angles to three instrumentally determined points are observed, then it is possible to compute the location of the unknown point and the azimuth of any or all three of the unknown lines. This is the three-point problem, familiar to all triangulators. If the two observed angles are carefully plotted on tracing paper, it is possible to shift the tracing until the three radial lines pass through the three corresponding known points, as plotted to scale on the drawing. The unknown station, which is represented by the point from which the radial lines diverge, is then located correctly with regard to the known stations. This graphic method of solving the three-point problem is known to all topographers and is commonly called the tracing-paper solution. It has the advantage that all the known points visible to the topographer can be utilized in solving the problem.

The best determinations of position and orientation are obtained by this method if the angles are large and the distances to known points are comparatively great. The tri-lens or four-lens type of photograph is superior to the single-lens type both in size of angle and in length of line available for orientation, and for this reason the single-lens type will not be considered in describing this method.

Multiple-lens photographs that will enable the map compiler to distinguish houses and other fine detail with reasonable certainty should have a scale of 1:20,000 or slightly larger. Compiling the map to approximately the mean scale of the photographs has the advantage that many of the data desired can be transferred directly from the photographs to the map with only slight adjustments in position. However, a map of a 15-minute quadrangle on a scale of 1:20,000 is large and hard to handle, and, if practicable, it should be compiled in quarter-sheet sections—that is, in 7½-minute sheets. The disposition of the control points over the area plays an important part in determining the size of the sections to be compiled as separate units.

The greatest speed in compilation will be attained in this type of work by compiling these units on tracing cloth or celluloid sheets. After determining an appropriate scale for the photographs covering a quadrangle, a polyconic projection should be made to that scale on celluloid or tracing cloth and the primary control plotted thereon. Each control point should then be carefully located and marked on the photographs by a small dot of red ink. To insure accurate positions and orientation of the photographs in a strip it is essential that one of these control points be located well to the outer edge of each A and C picture and a third point close to the center of the line of flight. This set of three control points must appear on two overlapping photographs. Careful inspection of the photographs should be made to determine where this condition is best fulfilled, and the compilation should be started at that point, for its accuracy is largely dependent on the correct disposition of these starting points. On the first photograph draw a short radial line in black ink or Chinese white through each control point from either the principal or the nadir point of that photograph. The principal point may be defined as the intersection of the optical axis of the camera lens with the plane of the photographic negative, and the nadir point as the representation on the negative of the ground point vertically below the camera at the moment of exposure. As the separation of the principal and nadir points on any photograph is due to the inclination of the camera that existed when the photograph was made, it follows that these points will coincide whenever the exposure is made with the lens axis in the vertical position.

In addition to the lines through each control point draw other short radial lines through other definite points that it is desired to locate carefully. These tertiary points, if they may be so termed, should be well distributed over the photograph, always including some to each side and along the forward edge. One tertiary point should always be chosen as close as possible to the radial line drawn in the direction of the center of the next photograph. If possible, identify on the first photograph the nadir point of the second photograph and draw a radial line through this point. With these radial lines drawn in ink on the photograph it is ready for use. Place the tracing cloth on which the control points have been plotted over this photograph and shift it until each plotted point falls on the corresponding radial line on the photograph. The photograph is then in correct orientation, and the nadir point or the principal point, as the case may be, is correctly located. Mark the position of the nadir point on the tracing with the number of the photograph for identification. From the point representing the nadir point trace the radial lines to the tertiary points previously selected on the photograph and to the point representing the nadir point on the next photograph. This photograph may then be removed from under the tracing. Prepare the second photograph by drawing short radial lines from the nadir point or principal point to the control points previously identified on the first photograph and to all tertiary points that are to be located, including all the tertiary points that coincide with those selected on the first photograph and any new ones on the forward edge of the second photograph. Draw also a radial line to the point representing the nadir point of the third photograph if it can be identified. The second photograph can then be placed under the tracing and oriented by causing the plotted control points to fall on the corresponding radial lines, as was done for the first photograph. This adjustment should be carefully inspected to see that the radial line traced from the nadir point of the first photograph to the point representing the nadir point of the second photograph actually falls over the nadir point of the second photograph. If this condition is satisfied, the photograph is probably well oriented, and its nadir point can be marked and numbered on the tracing. The radial lines to the tertiary points should then be carefully copied on the tracing. It will be found that the radials to a tertiary point drawn from the nadir points of the first and second photographs will intersect, but at a point that probably does not coincide with the image of the point on either photograph. This intersection, however, should be the true position of the point, regardless of any distortions existing in the photographs, if the angles of intersection are not too acute and the nadir points of the photographs are exactly known.

The third photograph is handled in the same manner as the first and second with the exception that the three original control points will not appear on it. Points located by good intersections must be used for orientation of this and succeeding photographs, until a photograph made where the flight again crossed a control line is reached. Points on this control line are then intersected on the tracing in the same manner as other tertiary points, and this operation is a check on the accuracy of the position carried forward by the photographs. The closure of this line on fixed points near the line of flight will probably indicate a small error in distance and a very small one in azimuth. If this error is very small it can be neglected in view of the large reduction to which the drawing is subjected before reaching the topographer, but if it is too large to be neglected the work should be repeated until the closure is satisfactory. The intersected points falling in the outer portions of the wing pictures may be expected to be out of position laterally, owing to the acuteness of the angles of intersection. They serve to orient the photographs, however, and the location of each is strong in the general direction of the radial lines, but their preliminary positions must be used with care in the final compilation.

In flying over a quadrangle to obtain multiple-lens photographs for use in mapping, the pilot will often either purposely or accidentally overlap one flight a considerable amount on another. This overlap is of great help to the map compiler, as it strengthens his work by eliminating the most acute intersections near the outer ends of the photographs, and moreover, it gives him many common ties between the two flights which will necessarily bind them together more rigidly than if the two flights overlapped but a small amount. Probably the strongest combination is obtained by overlapping the flights more than 50 per cent. This will result in a series of photographs showing on their outer wings about half of the area photographed on the central part of each photograph in the adjacent flights. Points along the center of a photographic flight are more accurately located than points shown elsewhere on the photographs, and if they appear on the wing pictures of the adjacent flight they can be used as points of control for that flight.

To make the best use of this method it will be necessary to build up the tertiary control net from the two or more overlapping flights simultaneously, assembling three pictures made in the first flight, then three in the second, three in the third, and so on as far as the large overlap extends. Intersections from other photographs in these flights can be built up gradually in the same manner, using a few photographs from each flight at a time. To work most rapidly by this method and to insure the use of the same points in the overlapping region, it is well to select and mark the points that will be used before undertaking the work of intersection. If difficulty is experienced in identifying the points readily, they may be numbered. The nadir point is more accurately located than other points of a photograph; consequently it should be identified on the wing pictures of the adjacent flights, if possible, and used as a fixed point in the control net.

The accuracy of acute intersections such as occur on the wing prints or tri-lens photographs is greatly increased when four-lens photographs are used, for these acutely intersecting lines may be strengthened by an additional line from the D photograph of the adjacent flight, provided that a normal lateral overlap of flights has been attained. This strengthens the entire compilation so much that rotation of the camera in its mounting in order to increase the angle of intersection on the wings, the usual practice with a tri-lens camera, is unnecessary.

If the scale of the projection has been carefully chosen to fit that of the photographs, it will be found that the tertiary intersected points that correspond to points near the center of the photographs agree very closely, but that those toward the outer edges will diverge. In flat country this discrepancy will be due to tilt of the airplane at the moment of exposure and will generally be exhibited as a reduction in scale on one side of the line of flight and a corresponding enlargement on the other side; in mountainous country it will be due to a combination of the displacements caused by tilt and by the relief of the terrain. The effect of this combination of two distortions of the image may be puzzling at times, for it is possible for the tilt to neutralize the effect of the relief on one side of the line of flight while increasing it on the other side. These two distortions occur in all aerial photographs, and their relations are so involved that they can be separated only by reprojecting the negative and eliminating the effect of the tilt. This procedure requires a knowledge of the elevation of ground points and special equipment for measuring the coordinates of these points on the negatives, and at present it is not practicable for small-scale mapping.

It is good practice to select road corners or bends in roads as tertiary points for intersection, as they serve the double purpose of controlling the map and building up the road net at the same time. If the road corners have been or can be located on the tracing by intersection, it will be an easy matter to build up the entire road net by simple inspection of the photographs if the roads are straight lines or by adjusting the intersected points over corresponding points on the photograph and tracing the roads directly if they are irregular.

After the roads have been satisfactorily located on the tracing it is well to introduce many of the more important fence lines. These also will serve a double purpose, for in addition to being helpful to the topographer in the field they break the area of the map into small units that are of great assistance in transferring details from the photographs to the base tracing. As many fence lines should be added as will be needed to limit the size of the inclosed parcels to 2 or 3 square inches on the map. Near the outer edges of the photographs these parcels may well be smaller, as the distortions are larger in this region and there is consequently more need for adjustment of the details. In sectionized country the correct positions of the fence lines are easily obtained, as each fence can generally be located by drawing a single radial line to the point where the fence intersects a road. As the road has previously been located, a single line cutting it at a good angle gives the true intersection. In the Eastern States, where property lines are irregular, it is difficult to locate the fences correctly, as the relief introduces apparent bends into them that are hard to distinguish from the real bends. Theoretically it is possible to locate these fences correctly by intersecting points along them at close intervals, but as the fence lines are not shown on the published map the result is not worth the time involved. Many fences are shown on the photographic base map, as they furnish some information concerning the country away from the roads, but it should be recognized that they are not located with the same care as roads. For this reason the topographer should not infer that his stadia traverse is in error should he fail to close on a fence line by a small amount. In wooded country that is being surveyed by means of a tape and aneroid barometer it is probably advisable to accept these fence lines as they are shown, for it is known that no very large errors of position exist in them.

When the area has thus been broken up into small parcels, the road and fence lines should be inked on the tracing in fairly heavy black lines. It is advisable to use only a single line for a road, as better positions can be obtained for houses adjacent to the road by so doing. The tracing should then be adjusted over the photographs and the details traced wherever the parcels have the same size and shape on both tracing and photograph. If the discrepancy between the tracing and photograph is small the detail on the photograph can be adjusted to an approximate position without difficulty. If the photograph is badly distorted it may be necessary to determine additional points on the tracing by intersection, thus further breaking up the area into parcels small enough to adjust with reasonable accuracy. As all portions of the area appear on at least two photographs it will often be found that an area badly distorted on one photograph is well represented on the adjoining photograph. In taking detail from the photographs the map compiler will find that he can distinguish and show with reasonable certainty houses, large buildings, minor roads and trails of sufficient importance to aid the topographer, railways, cemeteries, bridges, overhead and below-grade crossings, fences, and crop boundaries, grant lines, section lines and other civil boundaries, woodland areas, streams and water bodies, such as lakes, ponds, marshes, and small depressions holding water only during the rainy season. Familiarity with aerial photographs enables the compiler to distinguish usually between houses, barns, and schoolhouses, and in certain areas topographic features, such as cut banks and depressions, may be identified.

After all such detail has been traced it should be inked in black, using bold lines throughout. No time should be devoted to neat drafting, as this compilation is intended only as a guide to the topographer, and accuracy of position is the prime consideration. The photographic reduction to which this inked copy will be subjected before it reaches the topographer will sharpen it up, and if made too fine some of the detail might disappear in the process of reduction. It is generally advisable to give the exact outline of woodland areas and to indicate by means of the letter W or by the customary zigzag line that the area is wooded. Where details have been shown but not positively identified, an interrogation mark should be added to draw the topographer's attention to the fact that they may need correction. Features that are discernible but not identifiable should be outlined and questioned in the same manner.

The position of the center of each photograph and its number should be marked on the tracing in blue ink, which will preserve it on the original but will not reproduce on the field sheet. The points of control should be inked in black and marked in a distinctive manner so that the topographer can recognize them. The name of the quadrangle should be inked along the north edge of the drawing, and the quadrangle name, the file numbers of the photographs used, the scale of the projection, and the draftsman's name should be placed in the margin below the southwest corner.

The drawing is then ready for reproduction, and as it is on a medium greatly subject to uneven expansion and contraction, the usual graphic reduction scale should not be used, but the meridional distance desired in the reduced map should be given to the photographer. In this way the reduced drawing will be to the desired scale along the meridians but will probably be off scale a small amount in the east-west direction, on account of uneven expansion or contraction of the tracing cloth. This will not affect the accuracy of the field work and can be eliminated in reproducing the map for publication.

Photolithographic prints in nonphotographic blue are made on double-mounted paper, and additional prints in black are made on map paper. The black-line prints are made as office records and for the convenience of the topographer, as they are more legible than the blue-line prints. They provide a base on which may be shown information collected but not placed on the field sheet. Plate 29 shows one of these sheets as it goes to the topographer.

MOSAICS

For the interpretation of certain features of the terrain photographs are so much more valuable than maps that it may be advisable at times to assemble the photographs as a composite picture, rather than use them for map construction. Such composite pictures are called mosaics. They may be either controlled or uncontrolled.

Controlled mosaics may be used in map construction under some conditions, but their usefulness is generally restricted to the commercial field to meet demands for local detail in city planning, laying out power lines, and other projects of similar nature. For this reason their construction is described only briefly.

The fact that a mosaic will not be accurate in scale should not be overlooked. The type of topography, the character of the flying accomplished by the pilot, and the skill of the mosaic builder all have their effect on the scale of the compilation.

For uses in which accurate scale is not important and the relative position of local details alone is needed an uncontrolled mosaic may be used to advantage. In a mosaic of this type the photographs used in the compilations are tied together only by their images, and consequently any displacement of the image existing in the photographs, due either to tilt or to relief, will have its disturbing effect on relative positions and scale. The best mosaics of this type will be obtained where the terrain has but slight relief. Multiple-lens photographs are not satisfactory for mosaic construction, as even slight tilts distort the images on the wing pictures severely.

An uncontrolled mosaic may be built around a single photograph as a nucleus or it may be built laterally from a single flight accepted as a base flight. In building around a single photograph the prints are fitted together as accurately as possible by matching images, and when satisfactory junctions have been obtained they should be pasted down on compo board or some other firm mounting surface. In pasting the prints to the mounting board overlapping should be kept at a minimum, as it will increase the thickness of the mosaic in such portions and consequently increase the difficulty of obtaining an even illumination over the surface when it is copied photographically. Evenness of illumination is greatly improved by beveling the overlapping edges. Prints that do not match in scale the one that has been already fixed to the mounting board can be enlarged or reduced to fit. Such changes in the prints should be avoided if possible, however, for they can easily be the cause of much trouble if the photographs are distorted and not merely off scale. Any correction applied to a print that is off scale but not distorted will affect the entire print equally; but if an enlargement should be applied to a tilted photograph to make its contracted edge join another print, it will be found that the enlarged edge of the tilted photograph has been still further enlarged and the error on that side increased. In regions where the relief is sufficient to distort the images appreciably the photographs should be taken with very large overlaps and only the middle portions used in making the mosaic. This procedure reduces the effect of the distortion but does not eliminate it, and some difficulty is bound to occur in matching the prints. Moreover, the areas that stand above the accepted datum plane are bound to have a larger scale than the rest, and nothing that can be done to the prints will alter that fact.

A mosaic compiled around a single photograph, as just described, will have as a scale the scale of the nucleus photograph if the matching was well done. Some other scale can be obtained in copying if the distance between two positively indentifiable points on the mosaic is known, or it can be obtained in the original mosaic by photographing the nucleus print to the desired scale, and reducing or enlarging all other prints sufficiently to match it.

More accurate determinations of position can be obtained in an uncontrolled mosaic by building laterally from the photographs of a single flight laid down by the straight-line method of orienting prints, already described. This procedure gives a more rigid " backbone " upon which to adjust the prints than a single print used as a nucleus.

Controlled mosaics are more accurate in scale and position than uncontrolled mosaics but are more difficult to construct. Well-run transit lines furnish satisfactory control when points visible on the aerial photographs have been located by the traverseman, and records of local engineering offices can often furnish data of value for this purpose. Triangulation is probably the least satisfactory of all forms of control for mosaic construction, as the stations are usually few and very difficult to identify on the photographs. An approximate form of control can be obtained by enlargement of an existing map, although this method has the great disadvantage that any error in the map will be magnified in bringing it up to the scale of the mosaic.

If transit traverse is used to furnish control with the usual north-south direction of flying, it will generally be possible to find a control point at each end of a flight. The straight-line method makes possible good orientation of the photographs between these points, and by plotting the centers of the photographs in correct position with regard to the straight line the photographs are prevented from getting far out of position. The photographs of each flight that permits it should be tied down in the same manner. Advantage should be taken of any straight lines appearing on the strips laid down fitted to control by extending them as far as they appear on the photographs and holding the mosaic to them. Where control points are isolated the problem is more difficult, for it is necessary to build up straight-line control between each isolated point and the fixed strips already laid down. If the straight-line method is not used for this purpose, difficulty will always be experienced in obtaining the correct orientation and position for the photograph on which the isolated control point falls. The photographs of the mosaic that are not on lines connecting control points must be added by matching prints as in the uncontrolled mosaic.

The mosaic may be used in its original form or may be reproduced by photography in single sheets or in sections depending on its size and upon available photographic equipment. The reproduction can be made to any convenient scale.

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