MAPPING FROM TRI-METROGON AERIAL PHOTOGRAPHY

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PREFACE

The contents of this thesis were gathered during some three years of active service with the armed forces of the United States during World War II. The author believes that it is the duty of those teachers of engineering who have experienced service in the war to record various aspects of their contact with modern applications of science to the end that it will become more readily available to civilian usage when peace shall come again.

To the Council of the School of Engineering of the Oklahoma Agricultural and Mechanical College for their kind invitation to receive the degree of Civil Engineer, the author is grateful. To Dean Edward R. Stapley, to Professor Ren G. Saxton, to Professor Clark A. Dunn, and to Professor John E. "Dad" Kirkham go special appreciation for their approval of this thesis. Its preparation has been lightened by knowledge of their friendship and memories of the days when we were colleagues on the same campus.

Socorro, New Mexico,

October 1, 1944

MAPPING FROM TRI-METROGON AERIAL PHOTOGRAPHY

I. INTRODUCTION

1. The engineering profession may anticipate a widespread use of methods and procedure developed by the armed forces during World War II. These advances encompass all phases of the utilization of science, directed toward the single purpose of victory. But their application to peaceful pursuits will be no less effective. One useful development possessing increasing capabilities is aerial mapping by Tri-Metrogon. Developed in Alaska, in the early 1940's, this method has proved itself to be accurate, fast and economical. It is least affected by variations in flying and the need for geographic control is a minimum.

II. SCOPE

2. This discussion covers a brief treatment of the theory of planimetric mapping from high obliques, a detailed description of the steps involved in the preparation of planimetric maps from Tri-Metrogon photography, a description of the material and equipment used in plotting, an example of the time required for the various operations, and an estimate of the capabilities of such a system of mapping. A knowledge of radial line plotting and the slotted template methods of assembly is presupposed.

III. GENERAL

3. Ease of Flying. The method of aerial photography with the assembly of three cameras is designated as the Tri-Metrogon method. This assembly contains three cameras, one pointing vertically downward in the conventional manner and two mounted normal to the direction of flight, but at a large tilt from the vertical. The two oblique cameras are placed so as to cover above the horizon and to overlap the

area covered by the vertical camera, with about 14 degrees of overlap. All three cameras are interconnected so as to make exposures simultaneously and thus cover a strip of ground extending from horizon to horizon in a direction normal to the flight line. The net effect of this method of photography is to increase the width of ground covered by a flight of photographs and hence permit a wider spacing between flight lines. Experience with this method suggests that the precision flying required for vertical photography is not required for photography with the Tri-Metrogon assembly. Both of these factors operate to make the job easier for the photographic crew.

4. Time of Mapping. Because aerial photography with the Tri-Metrogon assembly is faster than with the conventional vertical camera, it does not necessarily follow that the mapping will be faster by using such Tri-Metrogon photography. The aerial photography is but a small part of the work of producing a map, but it has a great effect on the time needed in the subsequent work of compilation. With equipment and suitably trained photographic personnel available to secure vertical photography, the overall time of mapping will be less with such photography than when mapping with Tri-Metrogon photography to equivalent scales, accuracies, and amounts of detail. Many more operations must be performed by the mapping personnel in plotting the information from the obliques and the time required is proportionately increased. For equivalent accuracies and amounts of detail shown, the number of photographs needed to be processed is approximately the same for both Tri-Metrogon and vertical photography.

5. Charting. Tri-Metrogon photography is an advantageous type

for the preparation of small scale charts in undeveloped country. This has been particularly true of the large areas of remote country which have recently been covered with such photography for the purpose of preparing aeronautical charts. In such country, where the photographic season may be short, a great coverage can be obtained with limited equipment. As the large, natural features are the main ones to be chartered from such photography, satisfactory identifications for the purpose intended can be made at great distances on the oblique views.

6. Detailed Mapping. Photography from the Tri-Metrogon assembly can also be of some value for the preparation of more detailed maps. Although vertical photography is to be preferred for such uses, occasions may arise where existing Tri-Metrogon photography can be made to fill an immediate need. The vertical exposure of the Tri-Metrogon assembly has, of course, the same capabilities that any other vertical exposure would have. The oblique exposures can be made to augment the vertical and can furnish useful information for some distance out from the area covered by the vertical. This is useful in such projects as flood control or highway location. The distance to which indentifications can be made satisfactorily on the obliques will approximate the width of another strip of vertical exposures. This is not a sufficient distance to cover the entire area between flight lines as ordinarily flown with the Tri-Metrogon assembly. Therefore, such a detailed map produced from this method of photography must either be discontinuous or have areas centered between flight lines in which insufficient information has been plotted. It is possible, however, to plot with some degree of accuracy all of the detail that can be properly identified on the oblique exposures.

7. Plotting. The vertical exposures of the Tri-Metrogon assembly are joined in a minor control by the radial line method. Horizontal directions are determined from the oblique exposures so that they may be properly resected and oriented with respect to the radial line plot of the verticals. Additional horizontal directions are determined from the obliques for points midway between flights and these serve to tie the flights together. The operation is performed using a mechanical type of radial line system. Additional points lying between flights for control of the plotting are located by horizontal directions obtained from overlapping oblique exposures. The detail is compiled from the vertical exposures to the radial line plot by use of a vertical sketchmaster, which is a form of camera lucida, or any method that will permit adjustment of detail to the minor control points. The detail is compiled from the oblique exposures by use of a form of camera lucida known as an oblique sketchmaster. As its name implies, it is an aid to sketching the detail from the oblique photographs. It presents to the eye a rectified view which is superimposed on and adjusted to the minor control points established. The completed compilation is put through the necessary drafting and reproduction steps as for any other mapping methods.

IV. AERIAL PHOTOGRAPHY

8. Cameras, Installation, Flying. - a. Cameras Used. Either the K-17 or K-3B type cameras are used in the Tri-Metrogon assembly. In either case they employ the six-inch cone equipped with the Metrogon, wide-angle lens and a vacuum back magazine exposing a 9 x 9 inch negative. These cameras have an angular coverage of approximately 74° as measured across the axis of the focal plane. Thus three of them provide more than enough coverage for the 180° from horizon to horizon.

While the lens used in these cameras is known as a six-inch lens, the focal lengths of the actual lenses may vary from 149.2 mm. to 155.6 mm.

b. Installation. (1) The cameras of the Tri-Metrogon assembly have been installed in almost every type of aircraft from pursuit to heavy bomber. It is only necessary that the proper camera mountings can be arranged. Photography may thus be encountered from any one of these types. Since the type of aircraft varies, so also the method of installation must vary. Generally, the installation is of a fixed nature with the cameras rigidly secured to the frame of the aircraft. One of the cameras is mounted so that its optical axis points vertically downward and so that the sides of its focal plane are parallel to the axis of the aircraft. The two obliques cameras are mounted so that their optical axes are inclined at an angle of 60° from the vertical camera, one pointing to the right of the ship and one to the left. The oblique cameras are also mounted so that the sides of the focal planes are parallel to the axis of the aircraft. This mounting provides for an overlap of approximately 14° between the fields of coverage of the oblique and vertical cameras. With the aircraft in flight, the oblique cameras cover approximately 7° above the true horizon.

(2) It is evident that three cameras the size of the ones employed in the Tri-Metrogon assembly cannot be mounted very close together in the aircraft. The method of mounting varies widely in the different aircraft and so the distance between cameras also varies. It will usually be found that the greatest distance between any two cameras of an assembly is less than ten feet, Since the photography is performed at a great altitude, this separation becomes negligible and it may be assumed that all three cameras are exposing from the

same point.

(3) Although most Tri-Metrogon installations have a rigid connection between cameras and aircraft, some installations may be encountered where this is not the case. For instance it may occur that the vertical camera is mounted on the floating suspension provided in the ship for the usual type of photography. This camera might be manually controlled to maintain it in a vertical position throughout the small variations of the aircraft from level flight. The two obliques cameras might be mounted adjacent to each other on a common framework which in turn might be mounted at some other point in the aircraft. Thus there would be no constant relationship between the oblique cameras and the vertical camera although the obliques would have a constant relationship between each other.

c. Camera Mounts. The same manner in which the mounts for the cameras of the Tri-Metrogon assembly are constructed and the manner in which the cameras are set in the mounts do not lead to precision settings. Thus is found that the angle of 60° to which the oblique cameras are nominally set may be one or two degrees in error. The other angles of setting, that is the horizontal direction of the optical axes and the rotation of the cameras about their optical axes, may likewise differ by one or two degrees from the desired setting. Since some of the installations require that the cameras be reset every time they are used by means of a bubble and protractor, this setting will not remain a constant for any given camera and mount. It is further possible that by changing a magazine on the camera during the course of a day's operations, or by giving the camera an accidental shock while it is in operation, to alter appreciably the angular settings. The settings of the cameras can only be determined by direct measurement on the photographs obtained.

d. Exposures. The operation of the three cameras of the Tri-Metrogon assembly is controlled by a single intervalometer. At the moment, of exposure, the intervalometer causes solenoids in the bodies of the three cameras to be actuated simultaneously. The action of the solenoids is translated through a mechanical linkage to the shutter release in each lens and thus opens and closes the three shutters. It is possible that the mechanical linkage has varying degrees of free play in the three cameras which might produce exposures at slightly different times. This possible interval between the nominally simultaneous exposures can be but a small fraction of a second and probably is negligible. Further, since it is practically impossible to test and adjust this difference, the assumption of simultaneous exposures must be made.

e. Flying. Flying for the Tri-Metrogon photography is performed in practically the same manner as for vertical photography. The maximum possible flight altitude is used since the usable width of the ground covered by the oblique exposures is thereby increased and it permits a wider flight spacing. Exposures are made along straight and parallel flight lines at an interval that will secure a 60% overlap of the consecutive vertical exposures. This is the desirable exposure interval but it may be much shorter. With the cameras installed in pursuit type aircraft where there is no operator to determine the interval, it will probably be found that the overlap is much greater than the 60% desired. As the cameras usually cannot be manually controlled, their level is determined by the precision with which the aircraft is maintained in level flight. Likewise, since the cameras are secured to the frame of the aircraft, it is not possible to correct them for the crab of the plane. This is a troublesome feature of this type of photography. The operation of the cameras is in other ways identical to their use in vertical photography.

9. Information Required. a. General. Persons responsible for the preparation of maps from Tri-Metrogon photography must have certain information from the photographic personnel concerning the manner in which the aerial photography was performed. This information must include those things normally required to be known for vertical photography as well as certain additional information characteristic of the Tri-Metrogon method.

b. Installation. A complete understanding should be had of the method of camera installation employed. This is necessary to properly evaluate the reliability of the mounts in maintaining the angular relationships between cameras. The angles to which the cameras are set should be known along with the method by which the cameras are set to those angles.

c. Index. An index of the aerial photography should be obtained showing on the best map available the location of flights made, the direction of the flights, and the location, by number, of exposures along the flights. The aerial negatives should be numbered by any standard system that will provide for convenient indexing and filing. They should be numbered in a manner that will readily identify the obliques and vertical of a set that were exposed at the same time.

d. Camera Used. The records obtained on the photography should identify the negatives by number and roll as to the serial number of the magazine in which they were exposed, the serial number of the lens cone, and the serial number of the lens. The record should also show by serial number the equivalent focal lenghts of the various lenses used on the photography. This is the focal length as marked on the lens retaining ring and, in the absence of more complete information, must be used as the focal length of the camera using that lens.

e. Time of Photography. The records of photography should show the dates and time of day at which the exposures were made. The time should be recorded at the beginning and end of each continuous strip of exposures.

f. Camera Movement. The records of photography should show notations indicating the approximate exposure number at which any possible disturbance occurs to the camera. This is necessary to help locate any possible changes in the angular relationships between the cameras.

g. Camera Failure. The record should show notations of any possible camera failure during the flight and steps taken to remedy it during flight.

h. Flight Altitude. The record should show the flight altitude of the photography with all necessary corrections applied to secure the greatest possible accuracy in the height of the plane above the ground.

10. Materials Required. a. Number of Prints. The photographs comprise the largest item required as a result of the aerial photography. The number of copies of the photographs required for mapping will vary with the situation. In practically all cases, one complete set of contact prints will suffice for the actual work of compilation. There may be occasions, however, where additional copies will be required for other uses along with the map compilation. It is probably a safe practice to request two prints of each negative.

b. Type of Prints. To obtain the highest degree of accuracy in mapping from Tri-Metrogon photography, it is necessary that the prints to be used for the actual compilation be made on the highest grade of non-shrink paper or film base. The request for prints should stipulate the type of prints required. For the usual type of charting performed from this photography, prints on a good grade of double weight paper will suffice. The prints should be allowed to dry naturally following processing. They never should be "Ferrotyped" or put through a mechanical drier or print straightener. Single weight paper should never be used for prints intended for compilation purposes.

c. Fiducial Marks. The request for contact prints of the photographs required for compilation should emphasize the point that all fiducial marks must show on all prints. These marks in oblique photography are often obscured because they appear against dark sky or portions of the aircraft. They can easily be made to show on the print by inserting a small piece of paper of the proper density under their location on the negative while printing. It is essential that all marks be readily apparent on all prints.

d. Negatives. (1) One or two negative exposed in each magazine employed should also be requested along with the prints. As there are usually several waste exposures made at each end of a roll of film to test camera operation or to finish out a small remaining portion of a roll, these negatives should easily be obtained without harm to the file of negative comprising a project. These negatives should be properly identified as to the serial number of the magazine in which they were exposed so they may be used for measurements to determine print shrinkage and hence focal length adjustments.

(2) Appreciable shrinkage (or expansion) may take place in prints prepared on photographic papers. For the most part, this shrinkage will be uniform in both directions on a print and may be compensated

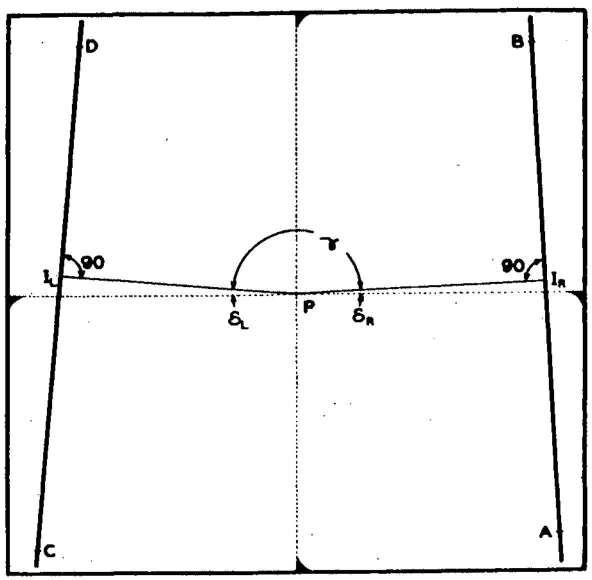


FIG. 1b

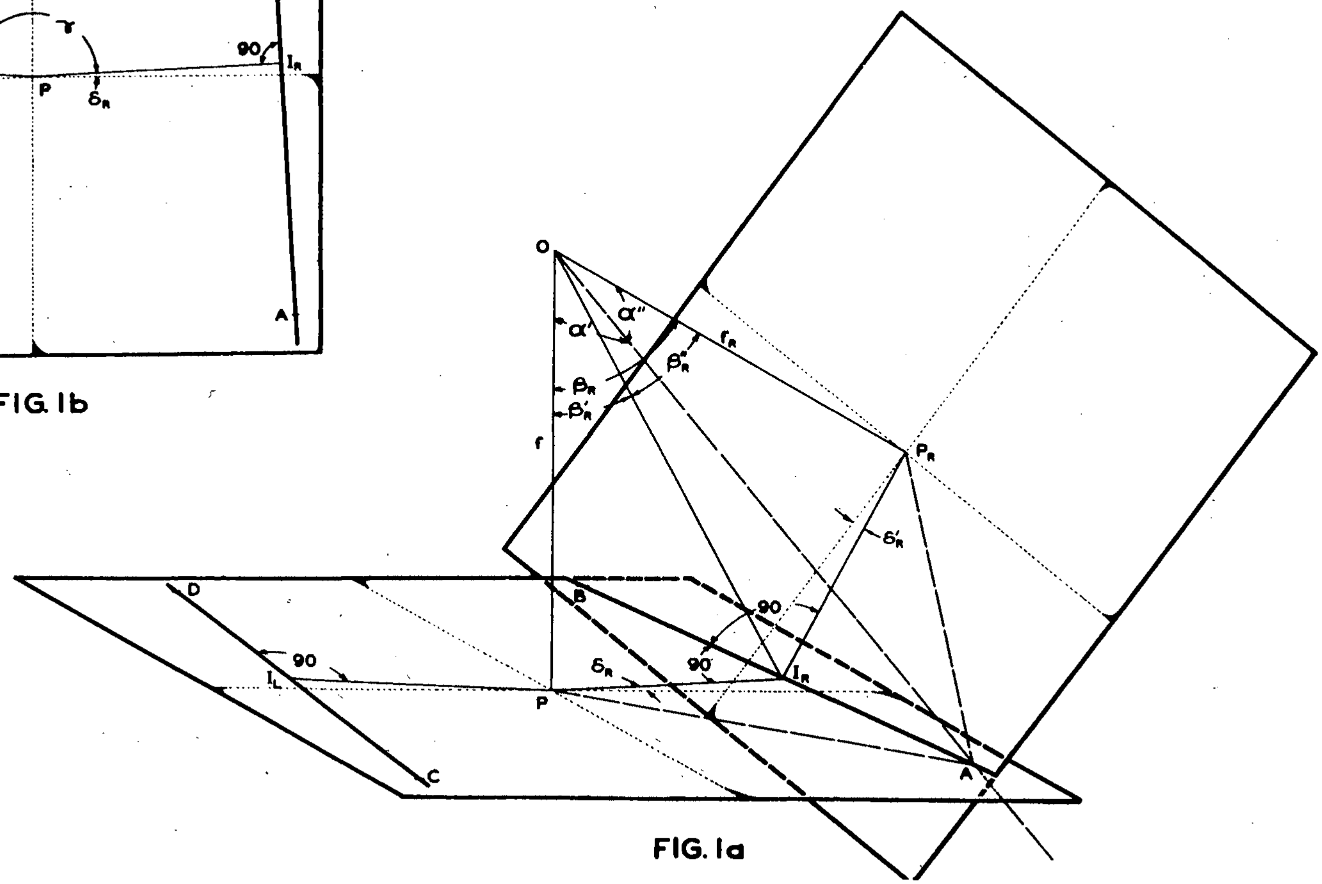


FIG. 1a

$$\alpha' = \tan^{-1}\frac{PA}{f}$$

$$\alpha'' = \tan^{-1}\frac{P_RA}{f_R}$$

$$OA = \frac{f}{\cos\alpha'} = \frac{f_R}{\cos\alpha''}$$

$$\beta_R' = \tan^{-1}\frac{PI_R}{f}$$

$$\beta_R'' = \tan^{-1}\frac{P_RI_R}{f_R}$$

$$\beta_R = \beta_R' + \beta_R''$$

for by adjusting the focal length. By measuring identical distances on film and prints such as between fiducial marks or edges of the focal plane frame, a ratio expressing shrinkage may be found. The focal length of the camera should be adjusted by the same ratio to secure the focal length of the prints. The negatives should be measured as early as possible following development so that prolonged aging will not affect their size.

11. Determination of Camera Settings. a. Angles Required. Illustrated in Fig. 1a are the vertical and one of the oblique positive prints of the Tri-Metrogon assembly. These show the relationships that is necessary to determine for the two cameras. Since it is assumed that all cameras of the Tri-Metrogon assembly expose their negatives from the same point, Fig. 1a represents both cameras having the same perspective point at O. The focal lengths, f and f_R, and the location of the principal points, P and P_R are known for the cameras involved. It is necessary to determine the angle β_R between the principal axes of the two cameras and the angle δ_R between the direction of the oblique principal axis when projected into the plane of the vertical exposure and the line between fiducial marks on the vertical exposure. This angle δ_R has no significance in itself but serves to determine the angle between the directions of the two oblique cameras. The difference in the value of δ_R for the right oblique and δ_L for the left oblique is the angle between the directions of pointing of the two oblique principal axes when projected into the plane of the vertical exposure.

b. Line of Intersection. To determine the angle it is first necessary to locate the intersection of the plane through the two principal axes with the planes of the two photographs since that is the plane in which the angle must be measured. This is best located by finding the intersection between the planes of the two photographs, the line AB in the illustration. Then the perpendiculars from P and P_R to the line AB will be the lines of intersection of the planes of the photographs with the plane containing the two principal axes. These perpendiculars will intersect the line AB in I_R. Then the tangent of the angle β'_R is determined by the relation $\frac{PI_R}{f}$ and the tangent of β''_R by $\frac{P_R I_R}{fR}$. It is seen then that $\beta_R = \beta'_R + \beta''_R$ and is the angle sought. Also, the location of the point I_R on the two photographs locates the lines PI_R and $P_R I_R$ and permits measurement of the angles δ_R and δ'_R thus determining all of the relations which define the relative settings of the two cameras.

c. <u>Method</u>. The position of the line of intersection AB of the two photographs planes is most readily established by a trial and error method. Near the mid-point of the overlap of the vertical and oblique exposures and as near the edge of the exposures as possible, some definite photographic image is selected. This image on both exposures then represents the intersection of the planes of both photographs with the ray from O to that feature on the ground. Such a point is represented by A. PA and $P_A A'$ are measured on the two photographs. Then the angles α' and α'' are found from the relations $\tan \alpha' = PA/_f$ and $\tan \alpha'' = \frac{PrA}{fr}$. Then the values of α' and α'' are used in the relation $\frac{f}{\cos \alpha'} = \frac{f_R}{\cos \alpha''}$.

If the values of α' and α'' satisfy this equality, then A is a point on the line of intersection of the two photograph planes. If the equality is not satisfied, a new position for A is selected and the operation repeated until equality is found. Two or three trials should be sufficient for this operation. A point B is then similarly found on the line of intersection at the other end and the two points are connected by a straight line. A check is afforded then by this line drawn on both the vertical and oblique photographs as it should pass through identical image points on both. Next a perpendicular is drawn from P and P_R to the line AB as located on the two photographs. This locates the point I_R and thus the angles β_R, δ_R and δ_L may be found. In the same way the line of intersection of the vertical photograph with the other oblique is found as shown in the line CD and the perpendicular from P located I_L and the angle δ_L is determined for that oblique.

d. Horizontal Angle Between Obliques. In Fig. 1b is shown a diagram of the vertical photograph with the two lines AB and CD. When the two angles δ_r and δ_l are combined as shown in the illustration, the angle γ is obtained which is the angle between the directions of the two oblique principal axes as projected into the vertical exposure. As the plane of the vertical exposure must be assumed horizontal, the angle γ then represents the horizontal angle between the directions that the two oblique cameras are pointing. The vertical camera will normally be held in a vertical direction within two or three degrees so the angle γ will be substantially without error when considered as the horizontal angle.

e. Determinations Required. The frequency with which the determination of the relative settings of the three cameras should be made will depend upon the type of installation used and the reliability of the mounts for holding constant relations. Experience after making a number of determinations for various types of installations will indicate what the frequency should be. At the start, deter-

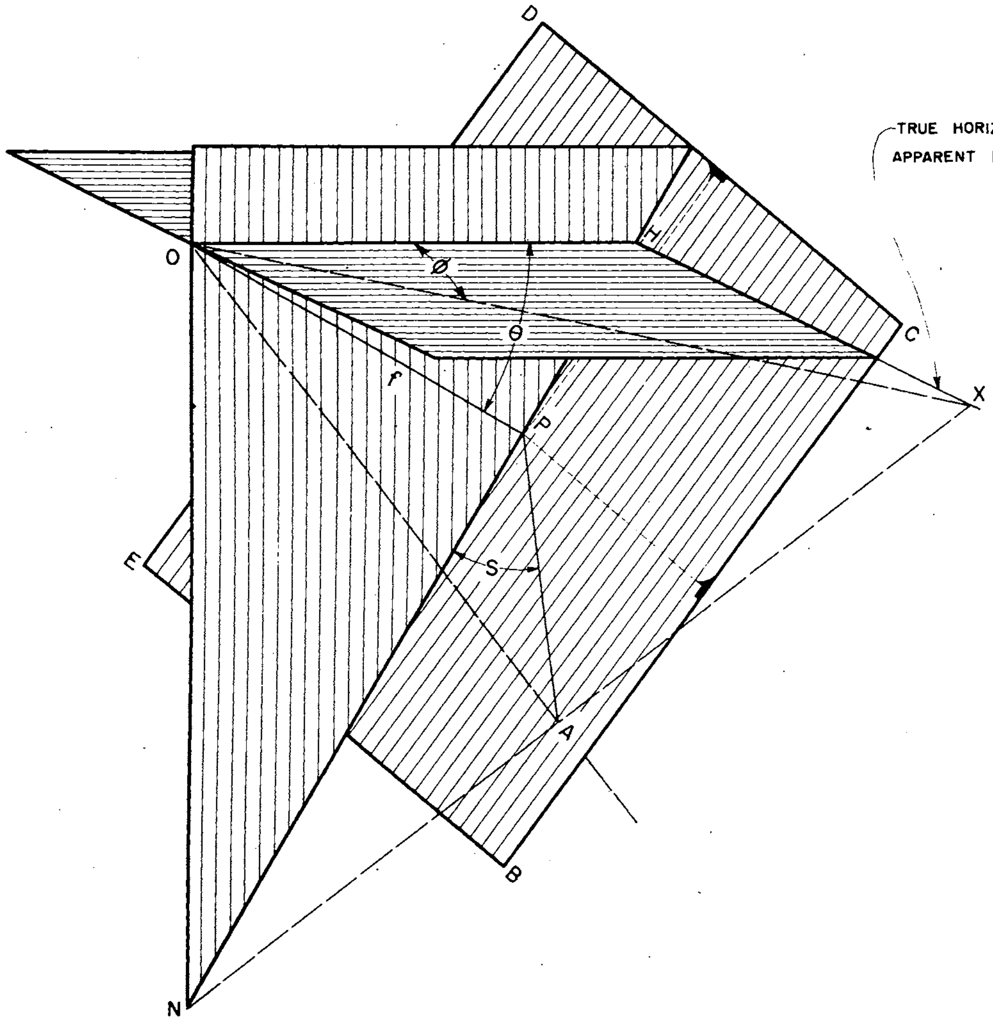


FIG. 2a

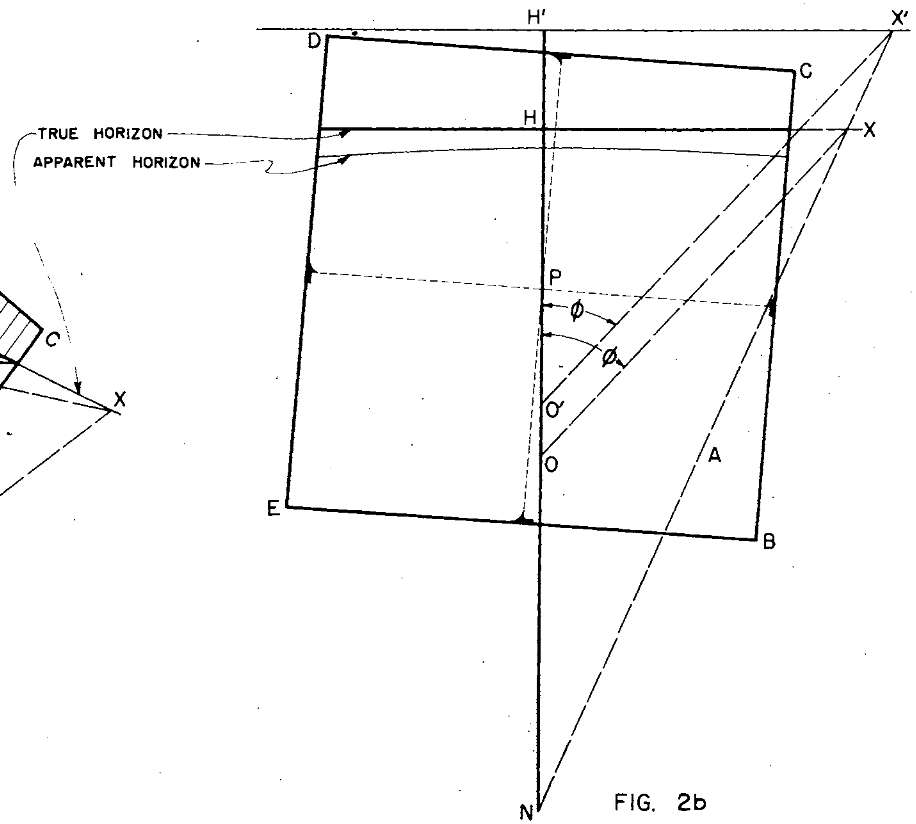


FIG. 2b

$$\cot \phi = \left[\frac{f \cos \theta}{PA} - \sin \theta \cdot \cos S\right] / \sin S$$

$$d\phi = \sin^2 \phi \left[\left(\frac{f \sin \theta}{PA \sin S} + \cos \theta \cot S\right) d\theta + \left(\frac{f \cos \theta \cos S}{PA \sin^2 S} - \frac{\sin \theta}{\sin^2 S}\right) dS - \left(\frac{3438 \cos \theta}{PA \sin S}\right) df\right]$$

when $d\phi$, $d\theta$, and dS are in minutes and df, f, and PA are in millimeters.

$PN = f \cot \theta$ $\quad PH = f \tan \theta$ $\quad OH = \frac{f}{\cos \theta}$ $\quad O'H' = NH' \sin \theta$

minations should at least be made at the beginning and end of every roll of film and at other points indicated by the record of photography where possible changes may have occurred.

V. THEORY

12. The Oblique Photograph. In Fig. 2a an oblique photograph is represented in the plane BCDE. The point O represents the perspective center or the point at which the exposure was made. The point P is the principal point on the photograph and f is the principal distance (focal length of the camera). The vertical line ON is the plumb line and it intersects the plane of the photograph in the point N, the plumb point. The plane ONP is the principal plane passing through the principal point and intersecting the plane of the photograph in the line NPH. A horizontal plane through O intersects the plane of the photograph in the line HX, the true horizon line. The line OA is a ray to some point on the ground and intersects the plane of the photograph at the image point A. The position of A on the photograph is defined by the distance PA and the angle S from the principal plane. A vertical plane OXN passing through the point O and the point on the ground contains the image point A and intersects the plane of the photograph in the line NAX. The angle ø between the principal plane and the vertical plane through O and A is the horizontal angle subtended at the plumb point by the principal plane and the point on the ground. The angle ø is also the angle between the lines OH and OX.

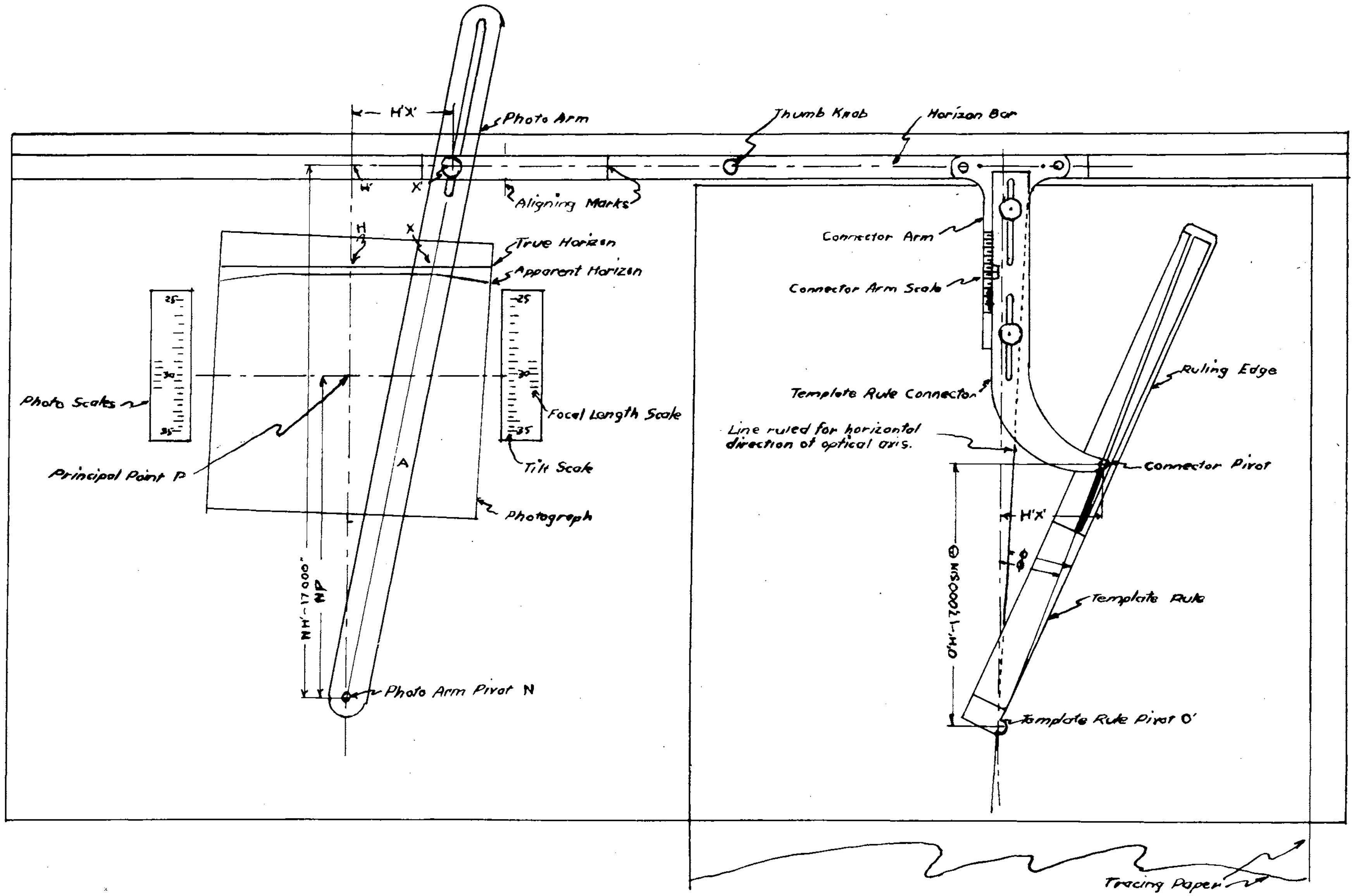
13. Horizontal Directions. Shown with Fig. 2a is the relation for the angle ø. It is seen that ø is only dependent upon that tilt of the photograph, ø, the location of the image point with reference to the principal plane, and the focal length of the camera. When these factors

are known, it is possible to determine the value of the horizontal angle at the plumb point between the principal plane and the direction to any desired point.

14. Determining Horizontal Directions. a. General. There are various means available to determine horizontal angles from oblique photographs. Regardless of method, all are dependent on the basic relation shown in the equation accompanying Fig. 2. All methods require that the tilt, position of the principal plane, and the focal length be known.

b. Methods. The most fundamental method of determining horizontal angles is by measurement of the quantities PA and S directly on the photograph and computation of the horizontal angles from the relation shown. Almost as fundamental is a graphical solution that required no equipment other than that usually available in a drafting room. An instrumental solution is the most direct. Various instruments have been used for this purpose.

c. Graphical Method. Horizontal directions are readily obtained by a graphical solution since it is seen from Fig. 2a that a line from N through A intersects the horizon line in the same point X as the horizontal direction line from O. By rotating the horizontal plane around HX so as to bring O into the plane of the photograph, the construction takes the form as shown in Fig. 2b. The construction lines may then be laid out on tracing paper with the distances OH, PH, and PN computed from the simple relations shown. By placing the tracing paper over the photograph, radial lines from N may then be drawn through desired image points to establish intersections with the horizon line HX. Radial lines from O to these intersections then give



H'X'
Photo Arm
Thumb Knob
Horizon Bar
H'
X'
Aligning Marks
H
X
True Horizon
Apparent Horizon
Connector Arm
Connector Arm Scale
Photo Scales
Focal Length Scale
Tilt Scale
Principal Point P
Photograph
A
NH'-17000'
NP
Photo Arm Pivot N
Ruling Edge
Template Rule Connector
Line ruled for horizontal direction of optical axis.
Connector Pivot
H'X'
O'H'-17000 SIN Θ
Template Rule
Template Rule Pivot O'
Tracing Paper

FIG. 3

the desired horizontal directions. Although there are other graphical methods possible, it is believed that the method illustrated is desirable as it permits easy computation of the distances required and permits a convenient arrangement for reducing drafting errors.

d. Angulator. The angulator solves the problem of horizontal directions much in the same manner as the graphical solution described above. By placing mechanical arms to represent the lines drawn in the graphical method and by providing certain mechanical linkages, the time required for obtaining the directions is considerably lessened. Instead of using the true horizon line in the solution, the angulator is based upon a line above and parallel to the true horizon. Such a line is illustrated in Fig. 2b as H'X'. It is seen from the illustration that such a line may be used if the center of horizontal directions is shifted from O to O'. Shown with Fig. 2b is the additional relationship required to determine the distance O'H' and hence to locate the position of O'. It is seen that O'H' is dependent only on the tilt, θ, and the distance NH'. By construction, the distance NH' as represented on the angulator is constant and so O' is then only dependent on the tilt. The general layout of the angulator is shown in Fig. 3. It is noted in Fig. 3 that the arm representing the line O'X' has been moved to right and downward to secure drafting space. It is then connected to the arm representing NX' so that the proper relationships are maintained. Scales are provided for locating the principal point of the photograph on the angulator and for adjusting the distance O'H' to the proper amount. It is still necessary to know the focal length of the photograph, its tilt, and the location of the principal line to properly set the photograph on the angulator.

15. Effect of Errors. a. Maximum Directions Errors. Also shown with

Fig. 2 is the differential equation which permits the determination of the effect of errors in the tilt, θ, the position of the principal plane as established by the angle S, and the focal length f, on the horizontal angles extracted from the oblique photograph. It will be noted that the effects of errors in these factors on the horizontal angle are greatest when the horizontal angle is greatest. This occurs for image points in the lower corners of the photograph. In the case of the oblique photographs from the Tri-Metrogon assembly, this maximum horizontal angle measured from the principal plane is approximately 56° 40'. For points in this position, the errors $d\phi$ in the horizontal angle due to errors in the tilt, ds in the swing of the principal plane, and DF in the focal length are as follows:

$$d\phi = 1.08\, d\theta$$

$$d\phi = .11\, ds$$

$$d\phi = 18.15\, df$$

Where $d\phi$, $d\theta$, and ds are in minutes and
df is in millimeters.

b. <u>Normal Direction Errors</u>. In the Tri-Metrogon assembly, the normal case does not require using the oblique photographs to such wide angles. Due to the overlap of the obliques with the verticals and the overlap in the line of flight, it is not generally necessary to use image points on the oblique photographs closer than 1½ inches to the bottom edge and 1 inch to the side. A point at this location has a horizontal angle of approximately 43° 25' and the errors in this angle due to the errors in tilt, swing, and focal length are as follows:

$$d\phi = .76\, d\theta$$

$$d\phi = .19\, ds$$

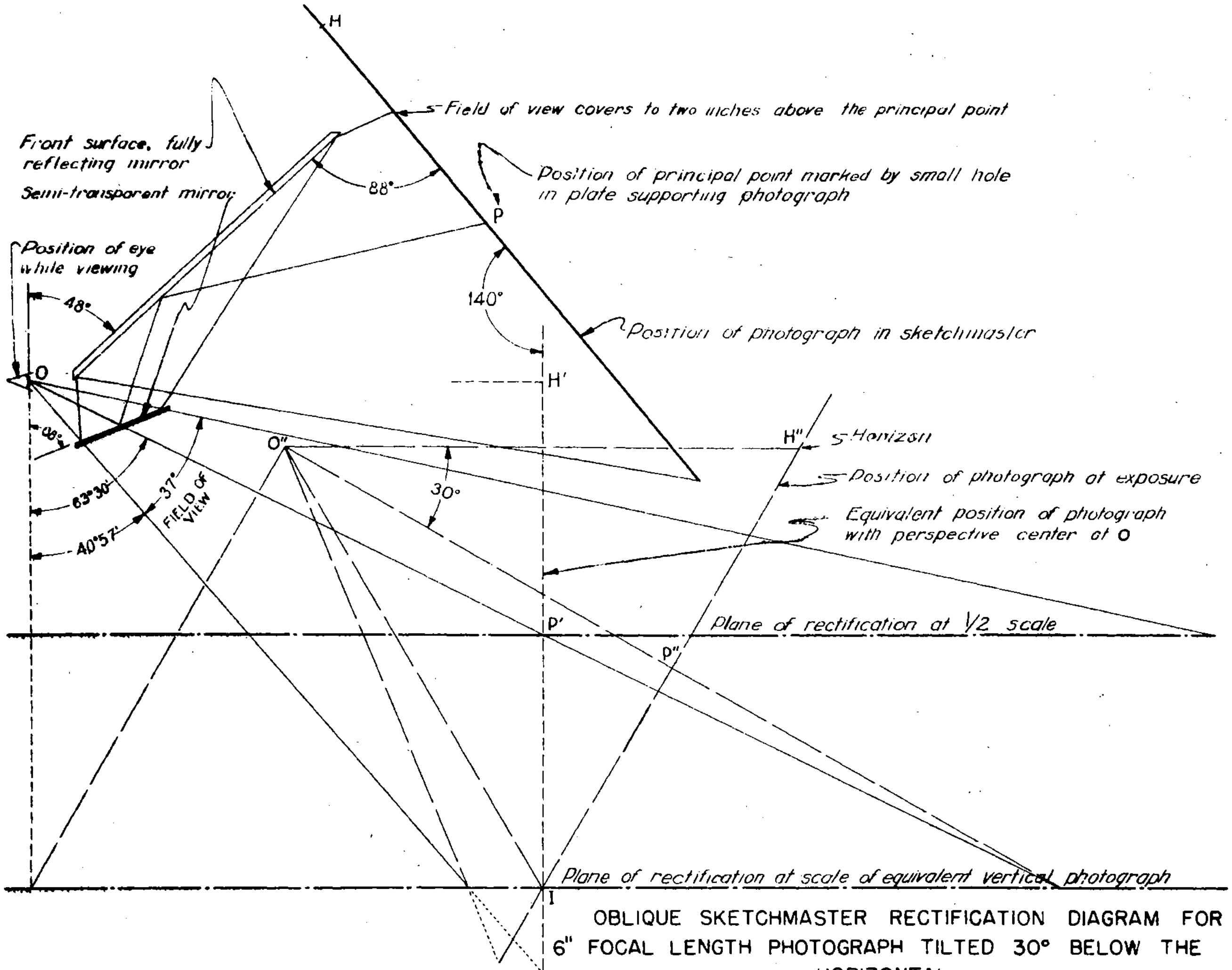
$$d\phi = 15.88\, df$$

Where $d\phi$, $d\theta$, and ds are in minutes and df is in millimeters.

c. Effect of Tilt Errors. It is seen from the above examples that the tilt used for the oblique photographs is the most critical factor as effecting the accuracy of the horizontal angles. It will be shown later that this is further so since the tilt is more indeterminate in the methods employing Tri-Metrogon phorography than the swing and focal length.

d. Lens Distortion. Distortion present in the Metrogon lenses will also affect the accuracy of the horizontal angles obtained from the oblique photographs. This type of lens has appreciable distortion which causes some errors to enter into the assumption that the photograph is a true perspective. This distortion will cause an error of some three or four minutes to occur in the horizontal angles obtained between points at extreme, opposite corners of the oblique photograph and will cause an error of two or three minutes in the horizontal angle obtained between a point in an extreme corner and a point approximately two inches in from that corner. Although it is possible to calibrate the lenses used and apply corrections for this distortion, it is not practically advisable for the relatively small errors introduced.

e. Paper Distortion. Distortion due to uneven shrinkage or expansion of paper on which the photog raphs are printed will also cause errors to occur in the horizontal angles. It is difficult to evaluate such possible errors but with improper processing of prints, this error can become quite large. If there is a large, uniform change in the size of the prints after processing, it will have the effect of changing the principal distance (focal length) of the print. This will have the same effect on the horizontal angles as errors in focal length and can be compensated for by adjusting the focal length according to the shrinkage or



OBLIQUE SKETCHMASTER RECTIFICATION DIAGRAM FOR 6" FOCAL LENGTH PHOTOGRAPH TILTED 30° BELOW THE HORIZONTAL

FIG. 4

expansion that occurs.

16. Oblique Sketchmaster. a. Principle. Illustrated in Fig. 5 is the principle of the oblique sketchmaster used in compiling the date from the oblique photographs. The photograph and the two mirrors are held rigidly together as a unit in the device. The unit may be raised or lowered as a whole so as to vary its distance from a horizontal plane on which the device rests during compilation. This provides for changing the scale of the rectification. Also, the unit may be tilted as a whole so as to change the tilt of the photograph with respect to the plane on which the device rests. This permits compensation for small variations in tilt from 30°. The device may also be tilted in a direction normal to the plane of the paper of Fig. 5 by adjusting the supporting screws so as to permit compensation for small errors in that direction. Although the device is designed for the purpose of compiling at one half the scale of the equivalent vertical photograph, it may be used for larger scales by using a block to raise the front supporting leg. It cannot be used for plotting at much less than one half the equivalent vertical scale.

b. Application. Although the principle of the oblique sketchmaster is theoretically sound for the conditions around which it is designed, the device is essentially an aid to sketchmaking. It is impractical to place and hold the eye while viewing exactly at the point O and hence the correct perspective is not recovered. Likewise, for tilts varying from 30° and focal lengths from 6", the true conditions are not obtained. However, the device does present a reasonable rectification and, when controlled and adjusted by a minor control plot, enables the detail to be compiled in its reasonably correct shape and position.

c. <u>Limitations</u>. The oblique sketchmaster as designed and built for work with Tri-Metrogon photography cannot be used with other oblique photography where focal lengths and tilts are materially different from those of the Tri-Metrogon oblique.

17. <u>Vertical Sketchmaster</u>. A vertical sketchmaster is used to compile the detail from the vertical photographs to a minor control plot. This device is similar in principle to the oblique sketchmaster in so far as the photograph and drawing paper are viewed by means of a semitransparent mirror so as to superimpose the photograph on the paper for guiding the sketching. As vertical photographs are used in it, the plane of the photograph is set approximately parallel to the plane of the paper. Provisions are made for tilting the photograph with respect to the plane of the drawing paper to compensate for small tilts. Provision is also made for varying the height of the device so that scale changes may be effected. Provision is also made for inserting lenses in the line of sight to the drawing paper to accomodate for the difference in viewing distance between paper and photograph.

VI. CONTROL

18. <u>General</u>. It is difficult to state the control requirements for mapping with Tri-Metrogon photography. Much depends upon the accuracy desired in the map the time available. As in other types of mapping methods, the resulting accuracy of map depends upon the amount and quality of the control used in its compilation. A map of some sort may be produced with no control. Such a map will be more in the nature of a sketch, will show correct relative shapes of features, will show no absolute positions, and will show distances to an accuracy dependent upon the knowledge of the flight height of the photography and upon the care with which the map is assembled. It is probable that most work performed with Tri-Metrogon

photography will be of this type as the tactical employment envisaged will not permit control data to be obtained.

19. Density. Where the situation demands that accurate tactical maps be prepared from Tri-Metrogon photography, it is essential that ground control be available. The use of Tri-Metrogon photography in mapping employs methods quite similar to the slotted template, radial line method of compiling verticals. Accordingly, about the same density of control will be required to secure equivalent accuracy. As the Tri-Metrogon method does not have so rigid a tie between flights, it probably requires some control in addition to that required for mapping from verticals alone. It is particularly desirable that control be located so as to be on or near the vertical exposures of the assembly at an interval deemed necessary to secure the desired accuracy.

20. Radial line mapping. The control requirements and methods of radial line mapping are identical for the Tri-Metrogon method and planimetry from vertical photographs alone.

VII. PLOTTING PROCEDURE

21. General. The procedure for mapping from the Tri-Metrogon photography is approximately the same in the preparation of maps of all types and accuracies. Some slight variations do occur due to differences in accuracy desired or equipment and material available. It is attempted in the following paragraphs to point out the various procedures that may be used and when they would be desirable.

22. Indexing. It is desirable that the most complete indexing possible be performed for the photographs to be used for the mapping work. If the indexes received with the photographs are not satisfactory, the first plotting operation should be their improvement. The index system should include the control information and other

data concerning the area to be mapped. Proper coordination of the later plotting operations will require that complete indexes be prepared to serve as bases for progress diagrams of the various operations.

23. Tilt Determinations. a. Use of Camera Settings. (1) Prior to any work of obtaining map data from the oblique photographs of the Tri-Metrogon assembly, it is necessary to determine the tilt and location of the principal plane for these photographs. The method of determining the tilt will differ for the various camera installations in use. The object of the determination is to obtain the tilt of a particular oblique camera when the plane is in its normal, level flight position. This value for the tilt may then be used for all photographs taken with the camera concerned as long as that camera maintains its setting with respect to the plane. This permits the smallest errors to be introduced into the value of the tilt used as the plane varies around its normal position. With excellent flying, it can be expected that the true tilt will differ by as much as one degree from a tilt value determined in this manner. More usual flying will introduce differences up to two or three degrees. As shown in paragraph 15b, these differences will lead to errors in horizontal angles of three-fourths this amount. It is possible to make individual tilt determinations for each exposure so as to secure an accuracy that would probably come within ten minutes, but this is generally not warranted except where the most accurate technical maps are desired.

(2) The computation of angles between cameras in the mounts as explained in paragraph 11 will indicate for how many exposures a tilt value may be used. If the computations show that the cameras always maintain the same relative positions, it is a fair assumption that they maintain the same setting with respect to the aircraft. In this case,

a constant tilt value can always be used for each camera involved. The method of determining that tilt value will vary with the installation used. For instance, there are some installations where the cameras are individually set in their respective mounts for each mission by means of a level bubble and protractor, the oblique cameras being set to an angle 60° from the vertical. If this installation is used, the rational method of tilt determination will be to average the three settings. First assume that the vertical camera was set truly vertical. Second, assume that one oblique camera was truly set to 60°, and, from the angle determined between that oblique and the vertical, determine the direction and amount the vertical camera would be out from the desired vertical setting. Third, assume that the other oblique correctly set and determine the error in the vertical camera on this assumption. The average of the three positions for the vertical camera should be used for its setting and used to compute back to the tilts of the two obliques.

(3) A complete understanding of the method of installation of the Tri-Metrogon assembly is essential in determining the tilt values to be used. Personal observation of the installation should be made wherever possible. It should be borne in mind that the tilt value desired is the actual tilt of the oblique camera measured from the true horizontal when the aircraft is in its normal, level flight position. This will be the average tilt value of the camera and hence will introduce the minimum of errors.

b. Use of Horizon. (1) The position of the horizon on the oblique photographs may be of some value in tilt determinations. If the actual ground or water horizon (apparent horizon) is visible, the tilt may be found to within a few minutes of accuracy. The dip of the apparent horizon below the true horizon may be found from the expression

$$\text{Dip (in seconds)} = 59\sqrt{H}$$

where H is the flight height of the plane in feet above the level of the ground or water forming the horizon. The barometric altitude of the plane is accurate enough for this determination. The dip added to the angle of the apparent horizon from the principal point of the photograph gives the tilt below the horizon. Care must be exercised so as not to select a cloud horizon as the ground horizon or to select the top of a high range of mountains in the background as the ground horizon. But where care is exercised, the horizon line can be of value. This may be particularly true where the greatest possible accuracy is demanded from the oblique photography.

(2) The position of any horizon, ground, cloud, or water, or the top of a mountain range at a great distance may also be of value in determining variations of tilt. Measurements to identical features near the horizon line on a series of exposures of a flight may be averaged to establish the normal position of the camera. The variations from that normal position may be used to compute the changes in tilt, and, if the tilt in the normal position is known from other sources, the individual tilts may thus be closely determined.

c. Locating Principal Plane. (1) The horizon image appearing on the oblique photographs is normally definite enough to establish the position of the principal plane. Although it may be a cloud horizon, it will be approximately parallel to the true horizon. The position of the principal plane should be established through the principal point and normal to the apparent horizon. This will probably introduce no error greater than 30 minutes, and usually less than 10 minutes, in the value of the swing angle. It was shown in paragraph 15b that the errors in horizontal angles are approximately two tenths of this error in swing.

(2) It is convenient to prepare a template on film base or transparent tracing paper to aid in marking the position of the principal plane. Two perpendicular lines arranged on the template so that one may be placed approximately over and parallel to the apparent horizon with the other passing over the principal point will serve this purpose. Marks made at the edges of the photographs by pricking through or ruling along the line passing over the principal point will indicate the line of intersection of the principal plane and the plane of the photograph.

(3) When the angulator is to be used to prepare horizontal direction sheets, it is preferable to mark a line perpendicular to the principal line and through the principal point of the oblique rather than marking the principal line itself. This may readily be accomplished by adding such a line to the template described above. It is only necessary to mark the ends of this line along the margins of the photograph. This line is then used in setting the photograph on the plotting board of the angulator.

24. Photographs to be Used. a. Normal Photography. As a radial line plot of the vertical photographs is made in the minor control plot, it is necessary to use all of the verticals for this purpose. The actual compilation of detail will normally require only alternate vertical photographs, however. Since the oblique exposures overlap each other 60% along the near edge in the direction of flight and about 80% along a line through the principal points, it is normally only necessary to use alternate oblique exposures. Where control points or other points of interest to be located in the minor control

plot fall in the foreground of the obliques, it may be necessary to use successive exposures so as to cover those points. It is essential that all points to be located in the minor control plot appear on at least two exposures. Where tactical maps of maximum accuracy are to be prepared, all exposures will be required. The prints necessary to use should be segregated from the remaining ones to eliminate excess handling.

b. Excessive Overlap. With some types of installations excessive overlap may be secured along the flights and it may be necessary to discard additional photographs. The vertical photographs to be used should be selected so that they overlap as closely as possible to the 60% desired. The obliques should be selected that accompany those verticals. These verticals and obliques may then be considered as the ones obtained had the photography been performed to the desired overlap. These may then be treated as in the preceding paragraph and those not selected may be placed aside. All future references to alternate exposures will mean the alternate ones of those selected.

25. Marking Principal Points. The principal points of all photographs required to be used should be located and marked as one of the first steps. This may be done by connecting opposite fiducial marks with straight lines or by use of a template. Such a template can be prepared on heavy film base so that perpendicular lines on it may be registered over the fiducial marks and a needle inserted through the intersection of the lines to mark the position on the photograph. It will be found convenient to indicate all principal points by a circle inked with a drop compass and centered at the point. The location of the principal points of the vertical photographs is next transferred forwards and backwards where they fall on overlapping exposures similarly marked. Transferring should be done while viewing the areas

stereoscopically and may be aided by a point selector. A circle inked on a piece of clear film base to the same size as that inked around the principal points can also serve as a means of transferring principal points under the stereoscope.

26. Minor Control Points. a. Verticals. Minor control points are selected and marked on the vertical photographs in the same manner as for the usual radial line method. Nine points per photograph are normally sufficient, the principal points previously marked and transferred serving for three of these points. In addition, all control points and points for which a position is desired in the minor control plot should be identified and marked. The points selected at the sides of the photographs should be selected as far out from the centers as possible so as to secure maximum strength in the plot. The side points should also be selected so as to lie on the oblique photographs and so as to be identifiable there. They should be marked on the proper obliques at the same time they are selected and marked on the verticals. Where crab is excessive in the photography, difficulty will be encountered in selecting the points along the sides of the vertical photographs so that they will lie on all of the obliques that they normally would. Where this condition occurs, it is not necessary to select any additional points since each oblique is used with the one opposite and the two will always contain at least four of the points from the verticals.

b. Obliques. (1) Minor control points are selected and marked on the obliques to serve in tying the successive obliques and the flights together. Where a strip of obliques is on the edge of an area to be compiled, the points should be selected along a line approximately through the principal points. Using only alternate exposures, this will permit a spacing of points so that three will occur on each oblique. By selecting a point near each principal point, this condition will be met. It is essential at least three points appear on each oblique and that each point appear on at least three obliques except for obliques at the ends of flights. These points are conveniently circled with a distinctive colored ink and assigned numbers. Beginning at one end of a flight they can be numbered successively up to twenty-five or fifty and then the numbers repeated. This will aid identification of corresponding rays needed to establish the intersection for the point in later phases.

(2) Between parallel flight lines, minor control points are selected approximately in the middle so as to appear about the same distance out on both sets of obliques. The poihts selected must be identifiable on both sets of obliques and must be spaced at an interval so that at least three will fall on every one of the alternate obliques used. Likewise, every alternate oblique must have three points each of which appears on two other obliques of the same flight. This condition will be met by selecting a point about a line midway between flights and about in the center of each of the alternate obliques of each flight. Where oblique exposures are located about opposite each other, one point will usually suffice for both. The points should be inked and numbered in the same manner as described in the preceding paragraph.

(3) In addition to the points selected as described above, all control points appearing on the obliques should be located on all obliques on which they appear, marked, and given an identifying control designation. To be of value, the control points must appear on at least two obliques. Occasions may arise where it is necessary to use an oblique additional to the alternate ones to secure this condition. Other points desired to be located in the minor control plot may also

be marked on the obliques and properly identified. All points described above for both verticals and obliques will be referred to hereafter as "minor control points" to differentiate them from the points described in the following paragraph.

(4) Additional points are selected on the obliques to control the compilation much in the same manner that a great number are selected for a detailed compilation by radial line methods from vertical photographs. The density to which they are selected and marked will depend upon the detail to be compiled and the scale of the final map. As a rough guide, they should be selected so as to be spaced at about two inches intervals on the scale of the compilation. The points must appear on at least two obliques in order to establish their position by intersection. Many will appear on three or more. It should be sufficient to mark them on three obliques. These points should be inked with still another distinctive color and assigned numbers to facilitate later identification. Points of this type are not included in the original minor control plot and will be referred to hereafter as "compilation points" to differentiate from the points of the preceding paragraphs.

c. Identification. (1) It is essential that all points be selected, marked, and transferred with the aid of stereoscopic viewing both with the vertical and oblique exposures. Great care must be exercised in selecting and marking points on the obliques for the appearance of features changed greatly from the first to the last exposure on which they appear. Stereoscopic viewing will greatly aid in evaluating the differences in viewpoint so that identical points will be marked. Stereoscopic viewing is difficult on obliques but can be used to advantage. Where crab is great, stereoscopic viewing in the foreground of the obliques may prove impossible.

(2) It is extremely difficult to locate identical points from two obliques taken in directions opposing each other. Great care must be exercised in this case. Viewing pairs from each flight stereoscopically will aid in eliminating errors.

27. Intensifying Detail. The methods used to compile detail from both the vertical and oblique photographs of the Tri-Metrogon assembly require that the detail to be plotted be intensified on the photographs. The devices used in the plotting result in a lack of contrast in the photographs as viewed and detail is indiscernible. As the detail must be intensified, it is a convenient operation along with which to select and coordinate the features to be plotted should be traced over with colored pencils or inks so as to obtain a dark and readily apparent line. A color legend should be established for the various features and classification symbols set up. With proper coordination and execution of this operation, the map will pass smoothly through the following operations with a minimum of checking and editing.

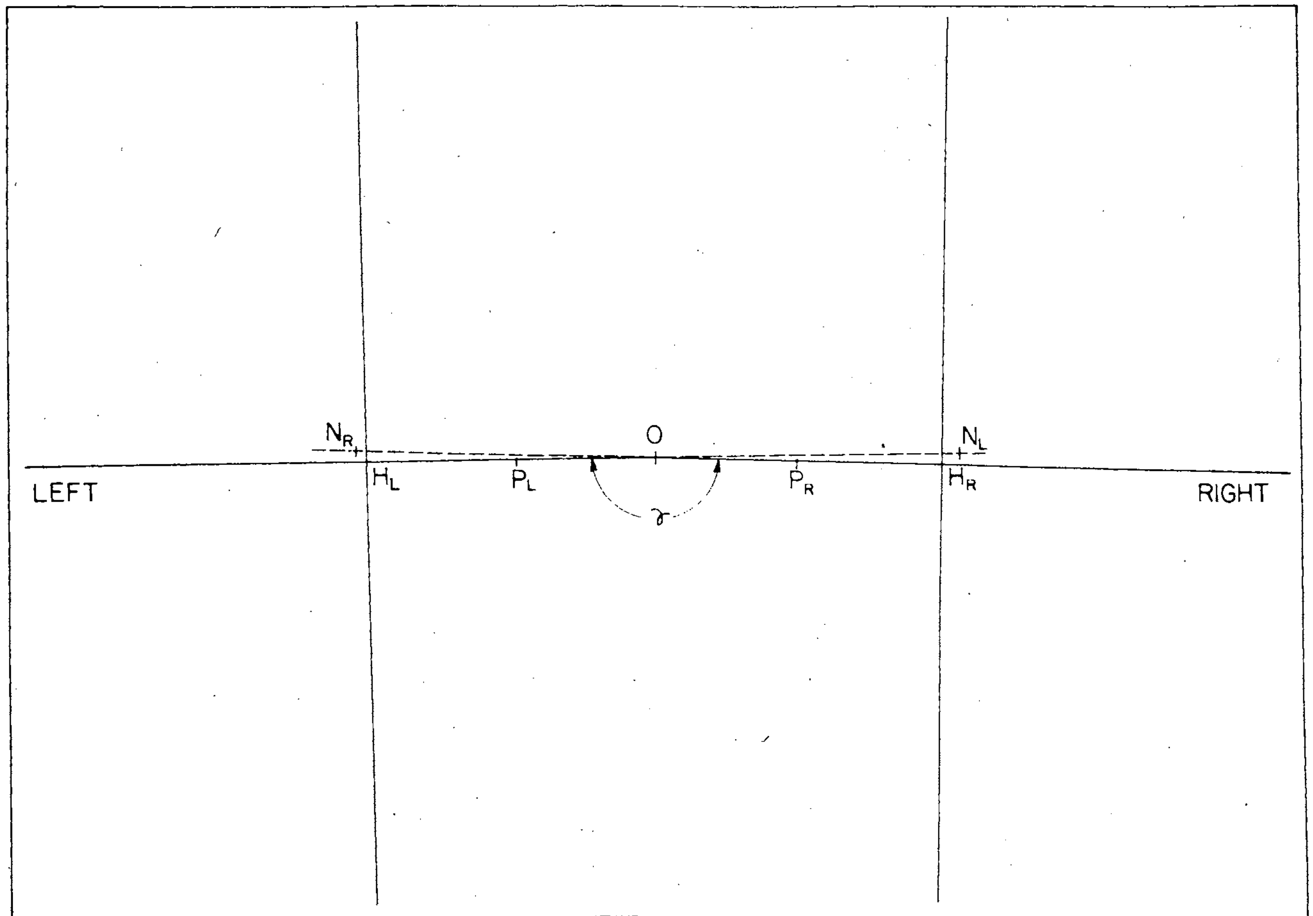
28. Radial Line Plot. a. General. Sometime following the selection of the minor control points on the vertical photographs and prior to assembling the oblique templates for the minor control plot, it is necessary to make a radial line plot of each strip of vertical photographs. This is necessary for two reasons. First, it furnished data for the approximate location of the oblique minor control points so that the slots may be properly placed and second, it furnished the data for connecting the plumb points of the oblique templates in the minor control plot.

b. Scale of Plot. The radial line plot is normally not made to control but is made independently to an approximate scale based on the flight height. Knowing the approximate flight height and the scale to which the minor control plot is to be made, the proper distance between principal points in the radial line plot may be determined so as to obtain approximately the desired scale. As the scale of the map prepared by these methods will generally be less than half the scale of vertical photographs, the radial plot and minor control plot should be at half the scale of the vertical photographs. This reduces the size of the work where extensive areas are to be covered. This is also the smallest scale to which the plotting may be accomplished as the range of the oblique sketchmaster is limited to this reduction. The scale of the radial line plot should be at the scale of the vertical photographs when a map at this or slightly smaller scale is to be prepared. Use of Tri-Metrogon photography for mapping at scales larger than the vertical photographs is not feasible.

c. Methods. The radial line plot of the verticals is executed to the desired, approximate scale by the usual methods. It may be either a graphical method or a slotted template method employing either slotted cards or slotted arms. If slotted cards are used for the oblique templates in the minor control plot, then it will be advantageous to use slotted cards for the radial plot of the verticals. If slotted arms are used for the oblique templates, than a graphical method for the radial plot will probably be best. The slotted arms for the radial plot of the verticals will achieve the desired results but probably require more time to use than the conventional graphical method. In any event, the radial plot should be made on a strip of tracing paper or acetate sheeting sufficiently long, and the positions of the minor control points marked thereon and clearly identified.

29. <u>Directions from Obliques</u>. a. <u>General</u>. Following the selection of minor control points on the oblique photographs and prior to assembling the minor control plot, it is necessary to determine from the obliques the horizontal directions to the points selected. These are horizontal directions from the plumb points of the exposures as discussed in paragraph 13 and 14. Directions to the points of both obliques of a set are determined and shown on the same piece of tracing paper. Both obliques of course have the same plumb point so the horizontal directions for both sides radiate from the same point. Further, since the horizontal angle has been determined between the direction of pointing of the two obliques camera axes in the computation of the camera settings, this fixes the relative position of the two groups of directions found from both sides of the set of obliques. Thus the directions to the points on each side of the vertical form a rigid assembly which can be resected on the radial plot by use of the directions to the points of the radial plot that were selected to appear on the obliques.

b. <u>Templates</u>. Tracing paper for the horizontal directions from the obliques should be cut and prepared in advance. The paper used may normally be of any type that is sufficiently transparent, but, where maximum accuracy is desired, it must be of a good grade having favorable shrinkage characteristics. It should be cut to a length that will be slightly greater than the spacing between flights at the scale of the minor control plot. The width of the paper should be slightly greater than the width covered by the obliques at the scale of the minor control plot at a point midway between flights. On a piece of the tracing paper, or film base of the same size, should be laid out the angle between the horizontal directions of the two oblique camera axes. This should be constructed with the angle point in the center of the piece of paper and



21" x 30" SHEET FOR SPACING OF 25 MILES BETWEEN FLIGHT LINES AND MINOR CONTROL PLOT AT A SCALE OF 1:80,000

SPECIMEN TEMPLATE FOR EXTRACTION OF HORIZONTAL DIRECTIONS BY GRAPHICAL METHODS

FIG. 5

the lines forming the angle extending in the long direction of the paper and about centered in the width of the paper. The angle point represents the point O of Fig. 2 which point is the same for both left and right obliques as they had the same exposure station. The left and right directions should be marked on the proper sides. This angle is next used as a template and traced on to all of the pieces of tracing paper cut. Both lines should be traced across the full length of the paper and their intersection clearly marked. The left and right ends should be clearly marked on each paper and the sheets may be numbered for each set of photographs they are to be used for. An example of a sheet prepared in this manner is shown in Fig. 5. The example also shows the additional construction lines needed for the graphical method.

c. Graphical Solution. When the graphical method of determining horizontal directions from the obliques is used, it is necessary to have some additional lines and distances placed on the template and traced into the tracing paper sheets. The position of the true horizon is located for each side of the set of obliques and measured out from the angle point, O. Perpendicular lines for the horizons are drawn at the distance OH_R and OH_L as shown in Fig. 5. The distances are determined as shown in Fig. 2. Between the angle point O and the horizons, the two principal points are located. Back on each line from the angle point O, the two plumb points are located. All are clearly identified and marked and traced onto the tracing paper sheets. To use the graphical method, an oblique photograph is placed under the proper side of the tracing paper, the principal point placed under the indicated mark, and the photograph rotated to bring the line normal to the horizon under the line OPH. The photograph and paper are secured in this position. Then with a ruling edge pivoted at the corresponding plumb point, lines are drawn through desired image points to intersect the horizon line. The ruling edge is next pivoted about O and the horizontal direction lines are drawn through the intersections on the horizon line as well illustrated in Fig. 2a and 2b. The direction lines are marked for proper identification. The directions for the oblique of the opposite side are obtained in the same manner using the other side of the template diagram.

d. Use of the Angulator. (1) The angulator is used mechanically to solve the graphical extraction of horizontal directions from the oblique photographs. The end product of its use is the same as that obtained from the graphical solution. The photographs are prepared as described in paragraph 23c (3) and tracing paper is prepared as described in paragraph 29b.

(2) Referring to Fig. 3, it is seen that there are two settings to be made on the angulator prior to its use. The proper position for the principal point of the photograph must be determined and the proper setting must be made on the connector arm. The formed operation actually determines the distance NP while the latter determines the distance O'H'.

(3) The photo scales provided on the angulator are for locating the position of the principal point and are laid out as determined from the relationship $NP = f \cot \theta$. The tilt scales are computed with f constant at 6 inches while the focal length scales are computed with θ constant at 30°. Thus it will be seen that neither of these scales can be used directly for all combinations of tilt and focal length.

(4) For tilts within one or two degrees of 30° or for focal lengths within approximately .04 inch of six inches, the scales are used in the following manner to locate the principal point. First the division of the tilt scale is noted for the actual tilt of the photograph. Next

the distance is noted on the focal length scales between the six-inch graduation and the actual focal length of the camera. If the actual focal length is greater than six inches, then the distance noted is added above the tilt division noted and determines the distance from the pivot for the principal point. When the actual focal length is less than six inches, then the distance noted is added below the tilt division noted at first. When tilts and focal lengths farther removed from 30° and six inches are encountered, then the distance NP must be computed and substituted in the relation for NP using a focal length of six inches and thus find the correct setting on the tilt scales provided.

(5) When the proper position of the principal point is found, it is easily indicated by a line ruled on clear film base. The line is made to pass over the proper scale divisions and the film base is secured to the plotting board with tape. Then with the aligning marks in coincidence, the photograph is slipped under the photo arm and placed with its principal point on the center line of the arm and with the line through the principal point and parallel to the horizon coinciding with the line set on the proper scale divisions. The photograph is then secured to the board in that position. The connector arm scale is then adjusted for the actual tilt of the photograph.

(6) The tracing paper templates are placed on the plotting board under the ruling arm which is easily removed for the purpose. The paper is placed so that the pivot point O' pierces the paper at the angle point laid out on the paper. With the rule back in position and the aligning marks in coincidence, the template is then rotated so that the line representing the horizontal direction of the optical axis lies along the ruling edge. The sheet is secured in this position. The line on the

photo arm is then placed successively over the various points on the photograph and horizontal direction lines of the proper length are ruled along the ruling edge. These are then marked with the proper identification. The horizontal directions for the opposite oblique are ruled in the same manner with the proper photograph in position for its tilt and focal length and with the tracing paper rotated through about 180° and aligned for the opposite side in the same manner as above.

30. Locating Slot Positions. a. General. The horizontal direction sheets obtained as in the preceding paragraphs are the basis of the minor control plot. Since the lines on a given sheet represent the horizontal directions from the plumb point of the exposures to the various points marked, it is possible by resection to locate the position and orientation of the sheet if the position of at least three of the points is known. If two overlapping sheets can be thus oriented, the position of additional points may then be determined by intersection. There are, of course, never sufficient known positions available to proceed in this manner. It is necessary to connect all of the sheets in a form of radial line plot to reach between available known control positions. The sheets as prepared contain all the data necessary to do this by the slotted template methods except for two things. There is no indication of where slots should be placed along the direction lines and there is no "azimuth" connection between successive plumb points. The radial line plot of the vertical photographs made at the approximate scale of the minor control plot furnishes these two missing items.

b, Resection on Radial Line Plot. The sheets containing the direction lines are next resected on the radial line plot. As the six points at the sides of each vertical exposure were selected so as to appear in the obliques, there will be six lines on each sheet to adjust to pass through six points on the radial line plot. In cases where crab is present in large amounts in the photography, four points may be all that will appear on the obliques. This is still one more than needed to establish the resection. With the sheets resected, it will be found that the point O representing the plumb point position probably will not coincide with the principal point of the vertical photograph as located in the radial line plot. This is because the presence of small tilts in the vertical photographs causes the plumb point to be displaced from the principal point.

c. Marking Slot Locations. Several horizontal direction sheets are resected on the radial line plot at one time, this being best done on a light table. It is then seen that the intersection of the corresponding direction lines establishes the position of the oblique points with reference to the radial line plot and hence at the approximate desired scale. The position of the intersection is marked on the lines of each sheet and hence shows where the slots should be centered. The intersections are marked for only the minor control oblique points as these are the only ones set up in the plot. Also with successive sheets resected on the radial plot, lines are drawn on each sheet showing the "Azimuth" lines to the oblique plumb points preceding and following. These lines need not be drawn if the slotted cards are used for the minor control plot.

d. Alternate Templates. It is only necessary to resect the horizontal direction sheets for the alternate sets of exposures as it is necessary to prepare slotted templates only for these in the minor control plot. Even though to use the Tri-Metrogon photographs for the maximum accuracy will require the use of direction sheets for all exposures, it will still only be necessary to use alternate sets for the minor control plot.

31. Slotted Templates. a. General. After the horizontal direction sheets are marked as above to show the approximate positions of the minor control plot. These may be prepared with the conventional cardboard material and a slot cutter or may be prepared from the mechanical, slotted template equipment.

b. Slotted Cards. To use the cardboard material, it should be prepared in advance and cut to a size corresponding to the size computed for the tracing paper direction sheets. The tracing paper sheets prepared and marked to show the location of the slots are placed over and secured to the cardboard cut to the proper size. The position of the plumb point is then pricked through onto the cardboard. Likewise, a prick mark is made through each of the direction lines for the minor control points at the position along the line as marked in the previous operation. The cardboard is then removed, the prick marks circled for easy location, the number of the exposure and the direction of flight (or right and left sides marked), and the numbers of the minor control points placed by the respective prick marks. The plumb point is then punched out with the center punch of the slot cutting equipment. The slots are then cut so as to radiate from the plumb point. Some difficulty may be encountered using the small slot cutter designed around a 9" x 9" vertical photograph for this purpose. By pricking additional positions for pivot points along the direction lines out near the distant slots, the slotting can be carried out satisfactorily. Following the slotting, the excess cardboard should be trimmed off so that the template takes about the shape of a rectified oblique. The plumb point pivot hole should also be punched out to about twice its original diameter.

c. Mechanical Slotted Template. (1) If the mechanical slotted template (slotted arm) equipment is used, the horizontal direction sheet is secured on a soft, wood drawing board or table. A threaded stud is pinned over the plumb point and smooth studs are pinned on the horizontal direction lines at the points indicated from the previous operation. A smooth stud is also pinned on each "azimuth" line about half way out to the position of the next plumb point. Slotted arms are then selected so that with the holes at one end placed over the threaded stud, the smooth studs will be about centered in the slots. A hexagonal washer is placed on the threaded stud on top of all of the arms followed by a round washer and hexagonal nut. With the double hexagonal wrench placed to hold both the hexagonal washer and stud, the nut is tightened with a socket wrench. The double wrench prevents any twist resulting from tightening the nut from being transmitted to the arms.

(2) Following completion of the mechanical slotted template, it is removed as a unit from the pins and given its identifying number. This is conveniently done by placing the number on a piece of Scotch tape attached to the template. Numbers are also advisable on the individual arms for easy reference in a later assembly of the minor control plot.

d. Plot without Templates. If the control density is great enough to fix the radial line plot of the vertical photographs to scale and position, it is not necessary to use slotted templates for the obliques. The horizontal direction sheets may then be resected on the radial plot so fixed and the intersections for all of the oblique points marked directly. This condition is desirable but is probably rare.

32. Minor Control Plot. a. Projection. A projection for the area to be mapped should be prepared in advance on a suitable material of a size large enough to cover the area necessary to be set up in the minor control plot at one time. Any type of projection which introduces negligible distortion for the area involved may be used. Normally, the polyconic projection will be found most convenient. The available control should then be plotted on the projection. Then the entire projection should be covered with tracing paper or acetate sheeting and the projection and control traced onto this material. Where the area is large and more than one strip of material is required to cover it, it is convenient to have the strips of sufficient width and so placed that the compilation of any one strip of photographs need not be placed on two sheets. A sufficient overlap should be provided between such strips of paper and the projection fully traced on each so that they may be properly registered again after any movement.

b. Template Assembly. Oblique templates are assembled in much that same manner as vertical templates in a radial line plot. In using the slotted cardboard templates, the vertical templates are assembled first. The oblique templates are then placed on top with the six slots passing over the proper six studs at the edges of the verticals and connected in the obliques with additional studs, the whole assembly being held by studs pinned at the control points. The mechanical slotted templates are assembled in much the same manner but do not require the vertical templates to be used. They require two studs placed in the azmuth arms between the templates so as to provide a sliding connection. It should be noted that in using the slotted arms, the radial line points at the edges of the vertical exposures opposite the principal points corresponding to the templates are not represented in the assembly.

c. Marking Points. After the templates are assembled and interconnected between control, pins are inserted through the holes in the studs and tapped so as to prick through the paper or acetate sheeting covering the projection layout. The templates are disassembled and the prick marks circled and given their identifying numbers. The exposure numbers are written by the centers of the templates to properly identify their location.

d. Compilation Points. The strips containing the minor control point positions may now be taken up from the projection layout and handled separately to obtain the position of the compilation points. On a light table, the oblique horizontal direction sheets are resected again on the minor control point positions on the strips and the positions of the compilation points marked from the intersections appearing for them. This completes the sheets up to the stage of the detail compilation.

33. Compilation. a. Verticals. The verticals photographs are best compiled first. The detail is compiled onto the sheets of tracing paper or acetate sheeting on which the minor control and compilation points are located. Normally, the nine points per vertical photograph which are located from the minor control plot are sufficient to control the compilation of the detail. Where maximum accuracy is demanded in the map, the minor control plot should be at the scale of the vertical photographs and additional compilation points then be "cut in" by conventional radial line methods. Tri-Metrogon photography should more normally be confined to the preparation of small scale charts and hence a less dense control for compilation of the vertical photo-

graphs is permissible. The vertical photographs may be adjusted to the nine points by use of a reflecting projector or the vertical sketchmaster if compiling at a scale materially different from that of the photograph. The reflecting projector is more convenient and faster to use but will seldom be available for such use. Sufficient instructions are usually furnished with the vertical sketchmaster to explain its operation.

b. Obliques. (1) The oblique photographs are compiled following the verticals on the same sheet with the aid of the oblique sketchmaster. The oblique photograph is placed in this device with the principal point over the small hole provided in the plate back of the photograph. The photograph is rotated so its horizon is parallel to the edge of the opening in the holding frame. Then with the oblique sketchmaster set over the compilation sheet with the viewing aperture approximately over the position of the plumb point for the exposure in use and the device pointing out away from the center of the strip, the photograph may be viewed so as to appear superimposed on the sheet of paper in its approximately rectified form. By adjusting the tilt and height of the oblique sketchmaster and by shifting its position as needed, the compilation points marked on the photograph are made to appear superimposed on their positions as determined on the compilation sheet. This adjustment is performed for successive groups of points including small sections of the photograph and, when coincidence is obtained, the intervening, intensified detail is traced off the sheet where it appears. Continual adjustment of the oblique sketchmaster will be found necessary.

(2) The lighting on the compilation sheet and on the photograph is quite critical and a source of constant annoyance. One satisfactory

solution uses a light table for the work. With the transparent compilation sheet on the glass surface, the light illuminates the sheet and passes on to illuminate the photograph. Control of the amount of light permits adjustments as needed. To reduce fatigue, the table top is best placed high enough as to be at about chin level for the operator when seated. As the oblique sketchmaster must be placed near the front edge of the table to permit viewing and the center of the strip of photographs on the sheet must be under the viewing point, it may be desirable to cut the compilation into smaller sections for this operation. This may be done by making a clean cut down through the center of the flight that has been compiled from the verticals. The pieces may then be rejointed later as required.

c. Drafting. After the compilation of the entire area or subdivisions thereof has been completed, the map may be put through the necessary remaining operations to secure the type of drafting and reproduction desired. One convenient system is to join and match as many pieces of the compilation sheets as required for a reproduction unit and copy photographically in this unit to a scale slightly larger than the final desired. From the negative, the desired number of blue line prints may be made for color separation drafting. The final ink drafting and lettering may be done on these blue line prints and the plates for printed reproductions prepared therefrom. The actual system used must be adjusted to the map desired and the equipment and personnel available.

34. Time Requirements. No great amount of information is available as to the time required for mapping with the Tri-Metrogon photography as yet. There is given in the following table, however, the time records

of a test project carried out using this type of photography. It is felt that the information contained therein will serve as a basis of time estimates in the absence of more complete data and will serve to show the proportion of the time consumed for the various operations. It may be of value in helping to plan the organization required for similar work. The data were collected on a test project covering 13,000 square miles for which a strategic map was prepared at a scale of 1:500,000. Three flights covered the area spaced at 25 miles. The photography was performed at 20,000 feet and the map compiled at a scale of 1:80,000. The work was performed by personnel entirely unfamiliar with oblique photographs and only slightly trained in the use of vertical photographs.

	Operation	Man-Hours	Man-Hours*	% of Total
1.	Indexing photography	15		1.3
2.	Marking and transferring principal points on verticals (223 photographs)	41.5	.186	3.7
3.	Marking principal points on obliques (236 photographs)	11	.047	1.0
4.	Marking principal plane on obliques (236 photographs)	11	.047	1.0
5.	Selecting and marking radial line points on verticals (223 photographs)	33.5	.173	3.4
6.	Selecting and marking minor control and compilation points on obliques (236 photographs)	79	.377	7.0
7.	Selection and intensification of detail on verticals and obliques	129.5		11.5
8.	Preparing slotted template cards for verticals (223 templates)	28.5	.128	2.5

	Operation	Man-Hours	Man-Hours*	% of Total
9.	Assembling slotted template plots for 3 strips of verticals (223 photos)	11.5	.052	1.0
10.	Computing camera settings (6 sets of exposures measured)	12.0		1.1
11.	Computing and preparing 2 oblique horizontal direction templates for each of 2 days flying	9		0.8
12.	Preparing tracing paper for oblique horizontal direction sheets (118 sheets)	4	.034	0.4
13.	Extracting horizontal directions from obliques (118 sheets, 236 photographs)	152	1.288 .644	13.5
14.	Locating slot positions on oblique horizontal direction sheet (118 sheets)	36	.305	3.2
15.	Preparing slotted template cards for obliques (118 templates)	32.5	.275	2.9
16.	Plotting projection and control and tracing to compilation sheets (projection 7 x 12 ft. in size)	38		3.4
17.	Assembling slotted template, minor control plot and marking points on compilation sheets	44.5		3.9
18.	Determining positions of compilation points	33		2.9
19.	Compiling verticals (223 photographs) (168 compiled with reflecting projector) (55 compiled with vertical sketchmaster)	63.5 (36.5) (27)	.285 (.217) (.491)	5.6 (3.2) (2.4)
20.	Compiling obliques (236 photographs compiled with oblique sketchmaster)	120	.509	10.6
21.	Copying original 7 x 12 ft. compilation to one/fifth size using copy camera	30		2.7

Operation	Man-Hours	Man-Hours*	% of Total
22. Preparing five blue line prints for color separating drafting	15		1.3
23. Finish drafting and inking	174.5		15.4
Totals	1129.5		100.0

Man-hours per sq. mi. mapped - .0869

* Per photograph, template, or sheet.

35. Guide for Plotting Operations. As a possible aid in the prosecution of a mapping project utilizing Tri-Metrogon photography, there is tabulated below the various operations that are required with a guide to their proper sequence.

Sequence	Operation	Prior Operations Necessary
1	Index photography	
2	Determine photographs required	1 1
3	Index Control	1,2
4	Identify control on photographs	1,2,3
5	Locate and mark principal points on verticals and obliques	2
6	Transfer principal points on verticals	2,5
7	Select and mark radial line points on verticals	2
8	Draw radial lines on verticals	7
9	Select and mark minor control points on obliques	1,2
10	Select and mark compilation points on obliques	1,2,9
11	Select and intensify on verticals and obliques the detail to be plotted	1,2
12	Compute camera setting	
13	Determine tilts of obliques	
14	Locate and mark principal line on obliques	5
15	Execute radial line plot of verticals	5,6,7,8

Sequence	Operation	Prior Operations Necessary
16	Prepare tracing paper for horizontal direction sheets	1,12
17	Prepare horizontal direction sheets for obliques	4,5,9,10, 12,13,14,16
18	Locate slot positions on horizontal direction sheets	15,16,17
19	Prepare slotted arm templates	18
20	Plot projection and control	1,2,3
21	Assemble slotted arm templates in minor control plot	19,20
22	Locate positions of compilation points	17,19,20, 21
23	Compile verticals with vertical sketchmaster	11,21,22
24	Compile obliques with oblique sketchmaster	11,21,22

VIII. ACCURACY

36. General. It is difficult to estimate the accuracy obtainable in maps prepared from Tri-Metrogon photography as its use is recent and sufficient tests have not as yet been made. Certain generalizations can be made, however, which can serve as a guide to interested officers in estimating the type of map that can be prepared from Tri-Metrogon photography available.

37. Accuracy of Position. As has been stated previously, positions can be plotted with about the same degree of accuracy as with radial line plotting with vertical photographs. To achieve such an accuracy, however, will require much more time than that shown in the table above. It would be necessary to determine individual tilts for each exposure used to obtain horizontal directions. This would require the changing of templates or angulator settings for each exposure used and hence require more time for the operation of obtaining horizontal directions.

Also, many more compilations points would be required to reduce errors of compiling with an oblique sketchmaster and hence greatly increase the time. But such a system is feasible and should result in a map containing position errors only slightly greater than one prepared from vertical photographs and the same control. Under the more normal method of using the Tri-Metrogon photography as outlined in the preceding section, the accuracy of position compares more nearly to that obtained by a mosaic laid by matching detail between vertical photographs and adjusting between comparable control.

38. Accuracy of Representation. a. General. More critical in the use of Tri-Metrogon photography is the ability to locate and identify the features to be plotted. As the scale on the oblique photographs diminishes rapidly in a direction away from the plumb point and as the angle of view becomes flatter, some point is reached beyond which it is not possible to identify features to be plotted. It is difficult to say just where the dividing line occurs. It can be said, however, that the limit for natural features is farther out than the limit for man-made features. For this reason, this type of photography is more suitable in types of terrain where the natural features are the prime ones to be plotted.

b. Cultural Features. Where man-made features must be plotted, the oblique photographs are not usable to such a great distance. It appears that the angle of view, rather than the scale, is the more critical factor in limiting the usability of the obliques. This limit, where such features are involved, is near the principal point. The features on the ground appearing at the principal point are at an angle of 60° from the plumb line of the exposure. With a flight altitute of 20,000 feet, these features are recorded on the photograph at a scale of about 1:80,000.

A test flight at 35,000 feet which results in a scale at the principal point of the obliques of about 1:140,000 still indicates that the detail is fairly discernable. Thus the usable width of a flight lies between the principal points of the two obliques of the Tri-Metrogon assembly. It should not be relied upon beyond that width to provide information for tactical maps for use of ground forces. This width between the principal points of the two obliques may be expressed readily in miles by multiplying the thousands of feet of flight altitude by two thirds. For example, a flight of 20,000 feet would cover approximately 13.3 miles between principal points. A project flown deliberately with this type of photography for the preparation of tactical maps should have a flight spacing sufficiently less than that amount so as to insure that none of the obliques need be used further than the principal point.

c. Charting Natural Features. Tri-Metrogon photography has been used quite extensively in preparing aeronautical charts of remote and undeveloped country with flights spaced at 25 miles. Under such conditions, many instances occur where the actual distance between flights is 30 miles or more. This requires using the obliques to a distance of 15 miles. With a flight altitude of 20,000 feet, this requires that the oblique print be used to a distance of about 1.75 inches beyond the principal point where the scale is approximately 1:160,000. The angle from the plumb line to features occuring at this distance is approximately 76°. It has been found that satisfactory charts can be prepared for such terrain with this flight spacing. This is stretching the system to the utmost, however, and probably a 20 mile spacing for such uses would be more advisable. It should, of course, be varied to suit the altitude at which the photography is performed.

VITA

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