pilot has to work with and the progress in that line. Did you ever hear a pilot say he had a real airplane for mapping or that he had a perfect set of instruments? Of course not. Because there is no such thing in existence. However, there are few pilots doing this work that do not have splendid ideas on what they want and need.

With so few days out of the year to fly it seems logical that more thought should be given to the assistance of getting more work out of these days.

It is my hope that this article will bring out many helpful ideas and stimulate further discussion on this subject. If it is so desired by any members of our organization I would be more than pleased to correspond personally with them on it.

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THE ORIENTATION OF OBLIQUE AERIAL PICTURES

by

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By the method described in this article, aerial oblique pictures may be oriented precisely through a procedure which might possibly appeal to the aerial map maker as possessing the indispensable quality of simplicity.

The procedure involves the use of a photogoniometer. Pictures corresponding to any ordinary focal length from 5" up can be used directly in this instrument and the total cost of the complete outfit, as used for making contour maps, aside from the transit employed is not over $200 and probably less if made in quantity. (Figure 1)

It is believed that the method might be useful in covering an area with control, both vertical and horizontal, where vertical aerial pictures are principally used for making the map.

A contour map worked up by methods similar to plane table methods involving resection and computation of altitude of the air stations and intersection and computation of the elevation of salient topographic points with subsequent sketching in of contours from the pictures is appended, and serves to show the possibilities of small scale topographic mapping by this method at least in mountainous country. Most of the work is graphical. All computations involved are trivial ones and are quickly performed on a slide rule.

Procedure of Orientation

A knowledge of the approximate altitude of the air station at the time of exposure, although not necessary, will save time. Therefore the altimeter reading is used as a preliminary.

It is necessary to have vertical and horizontal ground control available, but the control points do not need to be spaced closer than 15 to 20 miles or one point per 150 to 300 square miles where a wide angle lens is used or where two or more cameras are employed.

A typical map was made from 2-camera simultaneous exposures, the cameras, two K5s both being mounted in a casting at right angles to each other and constituting in effect a two lens camera.

A 5 or 6 lens camera designed for obliques and exposing the entire horizon on the same film could easily be designed and would reduce the work materially. With a single camera covering 40° of horizontal angle 9 exposures are necessary to cover the entire horizon. With two cameras at least 5 exposures are needed. With a lens covering 70°, 5 and 3 exposures respectively would accomplish the same result, while with a 5 or 6 lens camera a complete panorama could be made in one exposure. This means that the number of air stations that it is necessary to resect and the work necessary to do this would be reduced very materially.

To get back to the subject. If some sort of base map is available on which the triangulation points are shown, a rough location by eye is made of the camera station by simply inspecting the picture before us and lining up various map features using a plastacele ruler to define the center line of the picture on the map. This furnishes one line. The other picture belonging to the pair provides another line and we assume that the camera station is at the intersection of these two lines. In practice, using for example an ordinary National Forest base map which is a planimetric map, this location will be within 1/2 mile of the true position and most of the time will be within less than 1/4 mile of the correct position.

The pictures that are used at the beginning of the work are selected so as to show ample and advantageous control. Later as the work progresses, there will be a wealth of control available on most of the pictures. It is better if more than the necessary 3 control points are shown on each picture or picture pair. In mountainous country at least, ample control will always show on the pictures. Using the altimeter figure for camera elevation, the known elevation of the control points and the distances as scaled from the map, the corresponding vertical angles, allowing for curvature and refraction, are taken from the tables prepared for this purpose.

These angles are pricked off on the picture by means of a diagram which shows the linear values of vertical angles in different parts of the picture for the average tilt of the obliques.* A line is then drawn through these points which roughly represents the true horizon on the picture and which ordinarily may be within 5' to 10' or so of the true position in most cases.

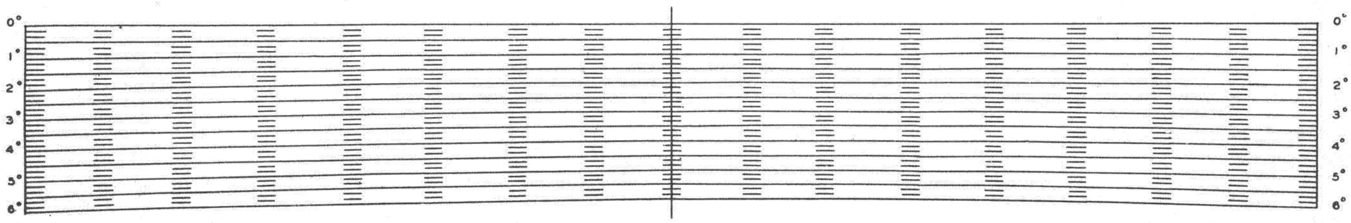

FIG. 2
VERTICAL ANGLE DIAGRAM FOR
AERIAL OBLIQUE PHOTOGRAPHS

Now, this line may not pass through all of the pricked points indicating that something is wrong; either the location or the assumed elevation, or, to a minor extent, our linear values for the vertical angles. Since a wrong location by 1/2 mile or so will affect the vertical angles to points 20 to 50 miles distant a very few minutes only, most of the error is usually due to a wrong assumption of elevation and the point nearest to the camera is affected the most. If this prick point happens to be below the line joining the two more distant prick points, it is evidence that the initial elevation assumed was too low. In that case a higher camera elevation has to be used.

When that is done, it is evident that the level line on the print will be raised higher than its first position and that it will rise twice as far in minutes for a control point 10 miles distant as it will from a control point 20 miles distant for the same change in value of the altitude.

By using the formula $x = \frac{a}{1 - \frac{d}{d'}}$ where x equals minutes of vertical angle required to raise the level line from the point pricked for the nearest control point to the new point, a equals minutes above or below the trial horizon of the pricked point corresponding to the near point, d equals distance in miles to the near point, d' equals distance to far point, we get an idea of how many minutes it takes to add to the value for the low point to catch up with the change in level at the distant points.

From the prepared table this gives the corresponding change in feet of the camera elevation and the number of minutes required to correct the level for each point.

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* This diagram is used for the purpose of expediting the operation.

The picture together with a straight edge coinciding with the new level line placed on top of it is now clamped to a piece of plate glass and set on top of the photogoniometer posts. The picture is tilted to its proper position as will be shown later and with the transit at the same level as the picture level line and centered in the focal point the vertical angles are pricked off more accurately. The horizontal angles are registered graphically by an arm at the base of the instrument which swings over a templet made of white opaque celluloid or metal. From this templet they are transferred to a sector made of frosted sheet plastacele and a resection is made on the map projection. (Figures 3 and 4)

With the new distances and the elevation previously used, the vertical angles are again checked and needed adjustments, if any, are made, using the same formula as before.

The whole procedure is simpler than it probably sounds. One soon gets into a routine and employs slight variations of procedure and manipulation to suit conditions.

For this preliminary work of resecting air stations points are used that are rather distant and not far below the horizon, perhaps up to 2 or 3 degrees.

After the level line has been precisely determined, closer-in points may be used for a more exact determination of the elevation of the air station, using vertical angles up to 10^{o} and distances down to 5 to 10 miles.

If no base map is available, a trial horizon may be drawn at random on the picture where experience indicates it is most likely to be located and the horizontal angles are measured on it and a preliminary resection is made in this way, taking care not to use points too far below the horizon. Horizontal angles do not change appreciably for a small displacement of the level line parallel to itself, or for a slight swing of this line if points close to the horizon are used. But a swing, even slight, will affect horizontal angles to points in the lower portion of the picture a great deal.

Where a pair of pictures are involved, they can, as far as the level line is concerned, be worked up independently, one serving as a check on the other one for altitude. The two sectors serving for resection are worked together, being slipped over the same center, which center is provided with a small hole barely large enough to pass a needle for pricking the position. (Figure 6)

If the horizon is known on one picture of the pair, a graphic solution will give the location of the level line on the other one whether this picture shows any control point or not. (See appendix Figures 9, 10, and 11.)

The two pictures may also be used rigidly together, i.e., the horizontal projection of the angle between optical axis of the two exposures which is the angle to use between the resection sectors may be set after having ascertained its value from another diagram. The use of this angle between two or more pictures is however unnecessary. (See appendix Figures 9 and 12.)

In a multiple lens camera for obliques used for this purpose it would therefore not be necessary to know the exact angles between the individual cameras, and the requirements for absolute rigidity of the instrument are therefore not so severe as for some other multiple lens cameras. A card with record of values used, points used for resection, vertical angles and computed elevations of intersected points, distances, trial and final elevation of air stations, etc., is kept for each exposure. If in pairs, the two exposures and the cards bear the same serial number preceded by the number of the roll.

After the air stations have been determined, other control or detailed points needed for the map work are intersected exactly as in plane table work and the elevations are computed. Horizontal angles are never read but are registered graphically only and are then transferred to the map projection.

The Photogoniometer

This instrument consists essentially of an ordinary surveyor's transit which is placed in the focal point of the oriented picture. The center of the telescope, the focal point and the level line of the picture are then in the same horizontal plane.

The focal point is bodily produced by means of the device shown in Figures 3 and 5. This attachment has a line (a) etched on the lower leaf about 1" below the intersection of the leaves. This line is perpendicular to the plane formed by its base, which rests on the picture when first placed in the instrument (Figure 5). The line represents the optical axis of the picture and carries a scale with a sliding index at the far end so that the focal distance may be adjusted for shrinkage of the print. In order to obtain this focal distance a scale is used so constructed that by placing it across the margins of the picture the corresponding focal distance is read directly.

The attachment described is clamped to the print and the glass, with the line centered on the pricked hole which marks the optical center of the picture. The picture mounted in this manner is then placed on the posts of the goniometer. The tops of these posts are V-notched to receive the sharp bevel edge of the straight edge and are free to revolve, making them self-aligning. One seat is adjustable toward the transit and the posts themselves are threaded and may be raised or lowered in their sockets to the proper height after which they are locked in place by locknuts (b) (Figure 1).

A tilting device (Figure 4) actuated by a wheel in front of the instrument bears against the back of the glass on which the picture is mounted. By turning this wheel the focal point is raised or lowered as the picture is tipped one way or the other.

The transit is mounted on a cross slide which slides on ways parallel to the level line of the picture. An ordinary lathe bed is used for this purpose and serves the purpose admirably.

The transit is first moved to one side on the ways, the telescope is leveled and is then turned parallel to the ways, in which position it reads zero. The tilting device is operated until the focal point rests on the horizontal cross hair. By operating the cross slide the vertical hair is then brought into coincidence with the focal point, the focal point attachment is removed by a twist of the upper clamps, the transit is moved along the ways by a hand wheel, turned 90° and set opposite the center of the picture. This point appears as a luminous mark on the picture as it is pricked through and is illuminated from behind.

Means are provided as mentioned before for raising or lowering the posts so as to bring the level line to the same level as the transit, also for making the level line seats parallel to the ways and for leveling up the entire instrument as a whole. Once these major adjustments are made they rarely need resetting. The templets used for transferring horizontal angles and for resecting positions are shown in Figure 6.

The picture is now oriented, i.e. it is in the same position as regards tilt and swing as it was when the exposure was made, and the transit is in the same position as it would be were it set up on a peak with the landscape before it.

Any marking to be done on the picture can be done while looking through the telescope, and the picture can be readjusted to any level line by simply lifting it off, adjusting the position of the straight edge and setting it back again.

The transit used in this particular instrument was a small mountain transit with full vertical circle. The objective lens was merely placed on an extension with adjustable cross-hairs just in front of the lens. The eyepiece was removed and a smaller hole used at this end.

<u>Accuracy</u>

With this more or less homemade instrument and with good vertical control, it is possible to read effectively vertical angles to within 1 or 2 minutes and to obtain elevations of intersected points differing less than 20 ft. as figured from 3 or more independent air stations. An effective accuracy of about 10 ft. in elevation is therefore probably obtainable for these points, if well defined. Horizontal positions check uniformly good without difficulty and identification of points offered no difficulty at any time.

Flying

After trying out various flight schemes on different projects, it was concluded that more or less complete panoramas supplemented by single exposures were most satisfactory.

As compared to flying for vertical pictures the job of covering an area with suitable obliques is extraordinarily simple.

There is no need for keeping a constant altitude, no need of keeping the ship level, no call for straight flying, for overlapping strips and exposures, no crab and no time interval to be considered; and the pilot need not necessarily have had previous experience in this line of work. Pictures are taken where they will do the most good from a mapping standpoint and sometimes the planned scheme is changed while in flight to suit the topography better.

The required turn in degrees of the ship when taking a panorama is made simply by bringing marks on the engine which include the proper angle as viewed by the pilot in range with distant points on the horizon, first one mark then the other. The photographer can without difficulty attend to both the navigation and the picture taking. Pictures may be taken on more or less cloudy days. Although it is desirable to have a good day a cloudless day is wholly unnecessary. There is little chance of any portion of the country being insufficiently photographed since the same topographic features will appear on many pictures at varying angles and distances. Probably many more pictures will be taken than are needed. Control as distant as 65 miles was used in preparing this map and this is by no means the limit.

General Remarks

Not all organizations are in a position to acquire expensive stereoscopic equipment while they might easily afford several instruments such as described. The method lends itself well to distribution of the work in several operations and the map work could be speeded up by using several instruments. At any rate this method of making topographic maps from aerial pictures alone was the only possible method available to the author. Aside from map making the photographs are valuable for many other purposes in connection with the work on the National Forests. As mapping photographs they were far superior to the ground photographs that were previously used principally because they cover vastly more ground and show topographic forms unobstructed. Field work aside from the photographic flight was entirely eliminated since the necessary control was already available.

As another illustration of what might be done with obliques, the author in the course of two days made a drainage map on the scale of 1/2" = 1 mile, using no equipment whatever except the prints and a ruler for lining up pictures and drainages of an area of some 1/4 million acres, which map, for practical purposes, showed no differences worth mentioning when compared with a map later worked up from General Land Office surveys except in one place where one short creek was in error 1/4 to 1/2 mile. This map was made without knowledge of the fact that the area had been surveyed and before the plats were available.

Appendix

When two cameras mounted at right angle to each other are used, it may sometimes be desirable to determine the position of the level line on one of the pictures from the line already determined on the other picture. It is assumed that one control point is visible on the picture to be oriented.

This is accomplished in the following manner:

Figure 9 shows the general geometry of the camera assembly. It is to be noted that the picture planes as drawn in full have lateral margins perpendicular to the plane through the optical axis of the cameras. Actually the camera backs are not in this position, but the cameras are turned around the optical axis and placed in their mountings so that the upper margins of the pictures when the cameras are tilted will be parallel to the skyline or the level plane HP'H" as indicated by the dotted outline of the actual photograph. In the calibration of the cameras shadow brackets are placed at points R, S, T and U. This is the line that the picture level line would occupy if the cameras were exposed with their focal planes in a vertical position. Actually the cameras are tipped about 12° when exposing. They hang naturally in this position in a shock cord suspension from an overhead bar.

Procedure

Lines O'P and OP are marked off on a base line (Figure 10) extended far enough to reach beyond R and U and a perpendicular PP' is erected at P, others at O and O'. The picture centering at O' which has the level line already determined is now placed so that the picture center covers O' and the brackets U and T coincide with the base line.

The level line H"H'" is extended to line PP'. The other picture is placed similarly on line RP. Line P'H is then drawn through the known point L on the level line for this second picture. The same diagram is used over again for all the pictures that are used in this way. Difference in focal length is taken care of by construction indicated below the base line.

Figure 9 will also suggest how the level lines are constructed when 3 points only are available for control on the two pictures, or when there are 3 on one and none on the other. The cross lines UR, HH'', TS and H'H''' are then used as indicated in Figure 11.

The horizontal projection of the angle between the optical axis of the camera which may be desirable to use in resecting, angle O"FO"', may be found from a similar diagram (Figure 12), suitably arranged by constructing the triangle FP'O"'. FP' is obtained from triangle FPP', FO'" is obtained from the right angle triangle FO'O'" and P'O'" is obtained from the figure P'PO'O'". All the necessary construction is shown on Figure 12. FP, OP, O'P, and FO' and the angle PFO' are always the same so that if the diagram is used over and over again, the new construction each time amounts to very little.

Figure 10

Level Line Determination

CASE 1. Level on photo A known and one point on photo B. Place pictures in position as shown and draw the level line P'L. If focus for O is shorter, use dotted construction and draw line P"L from P" on line P'F. (a) is the amount of shortage in focus.

CASE 2. If level line on photo B is known but nothing is known on Photo A, draw triangle PFP'. Mark off twice the difference between a and c along a paper edge and set off the remainder of the distance c at x. Repeat the same for b and d and obtain y. The level line on photo A should pass through these two points. An inspection of Figure 9 and Figure 11 will aid in visualizing this. All the lines shown on the diagram are drawn in permanently except those changing with different pictures as do the radiating lines from P'. Thus the diagram may be used repeatedly and the operations confined to merely drawing 2 or 3 straight lines for each new pair.

Figure 12

To find horizontal projection of angle OFO' Figure 9.

Given: Figure FOPO'

Procedure: Strike arc r = O'O'" center in O'.
Strike arc r = FO'" center in F.
Draw tangent P'O'" and strike arc r = P'O'", center in P. Angle PFB is equal to 1/2 of the angle sought. This diagram is also used repeatedly for other picture pairs.

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Editor's note: Certain maps, referred to in Mr. Wernstedt's article as are not being reproduced because of the necessity for conserving space.

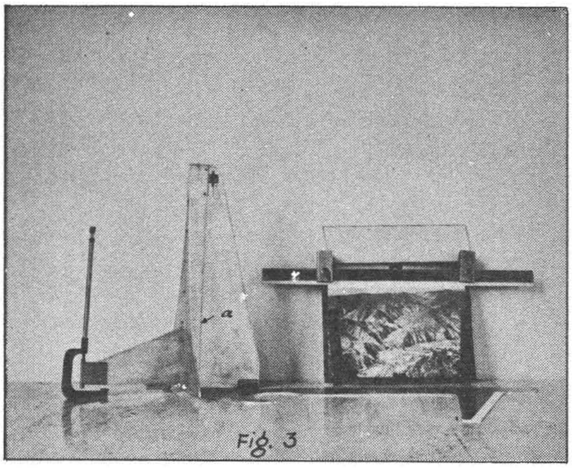

Fig. 3

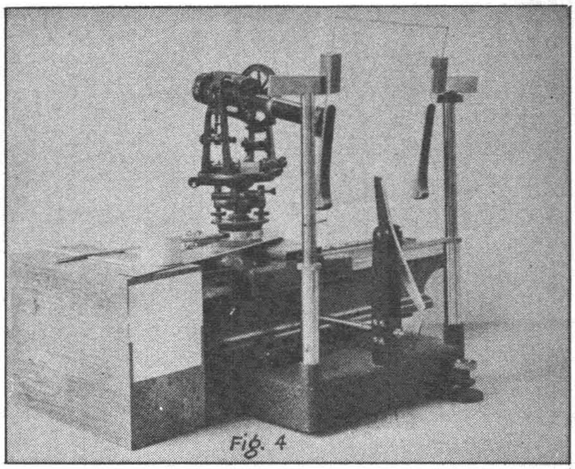

Fig. 4

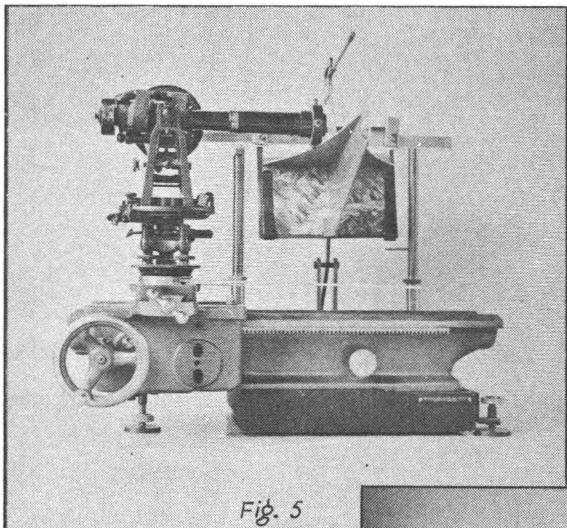

Fig. 5

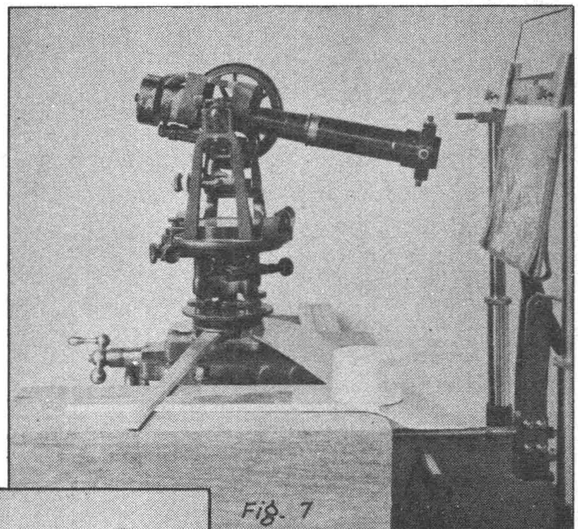

Fig. 7

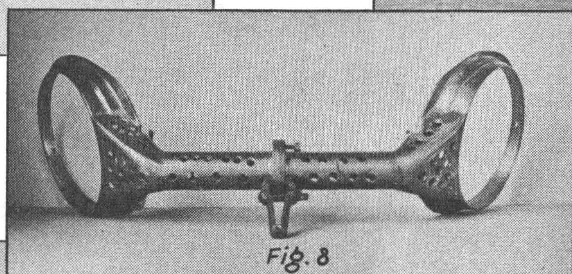

Fig. 8

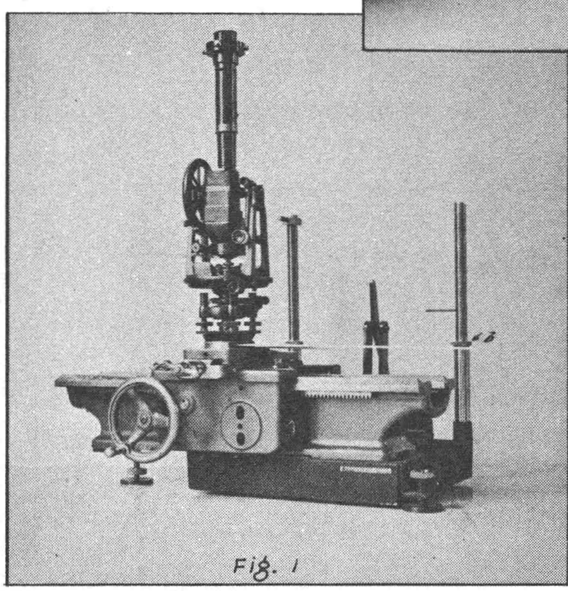

Fig. 1

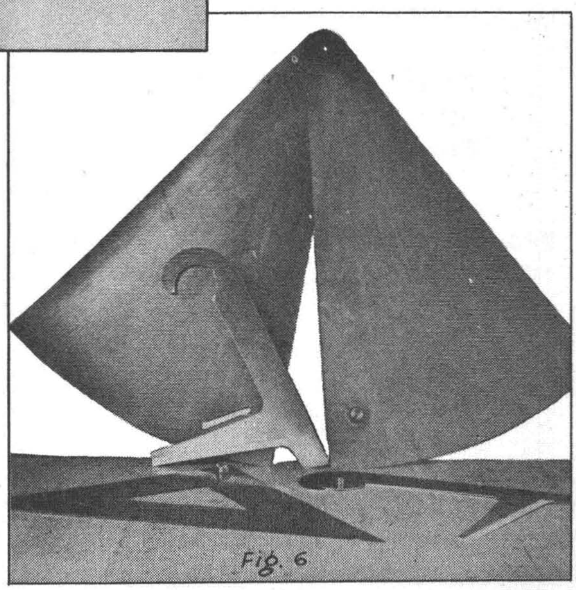

Fig. 6

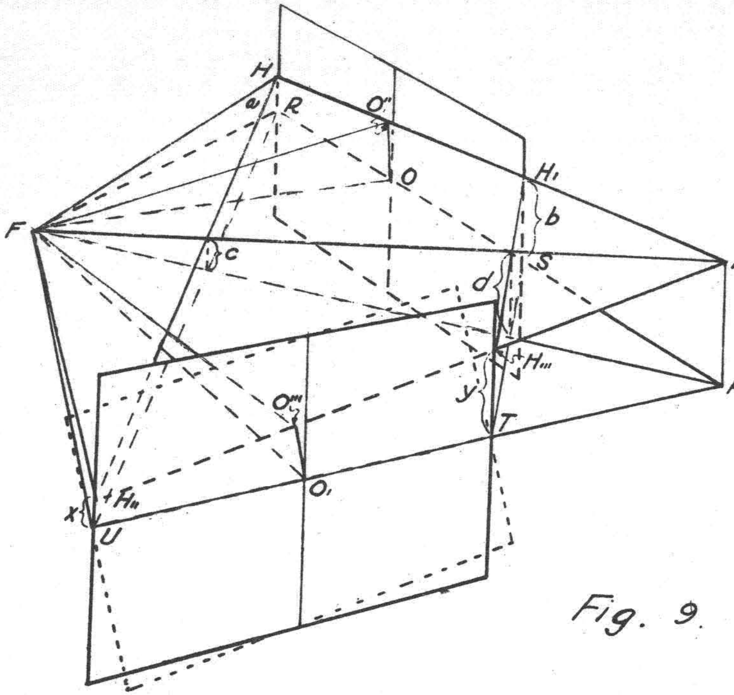

Fig. 9.

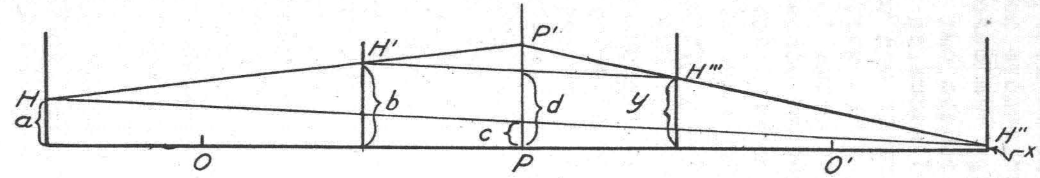

Fig. 11a

Projection on a plane perpendicular to FRPU of portions of Fig. 9

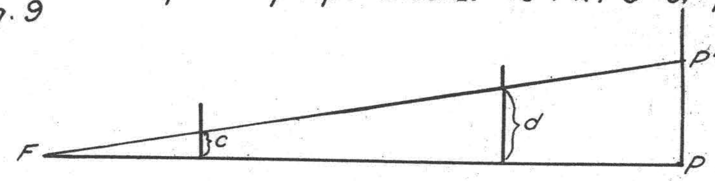

Fig. 11b

Triangle FPP furnishes distances c and d

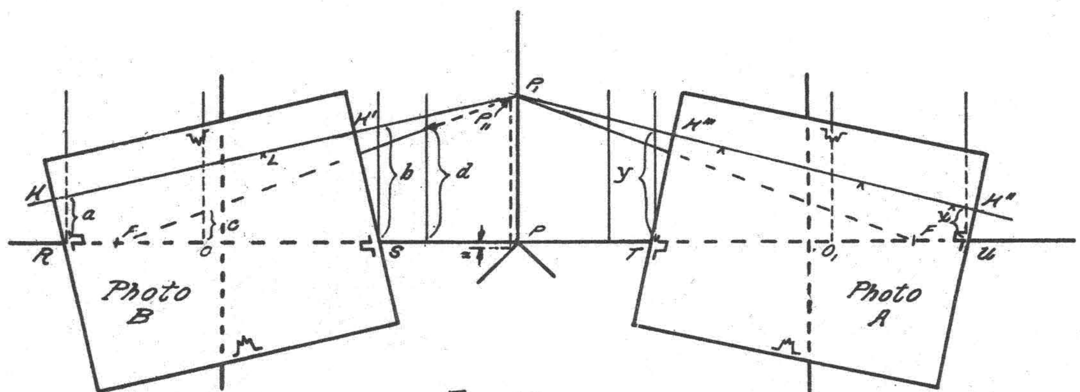

Fig. 10. –

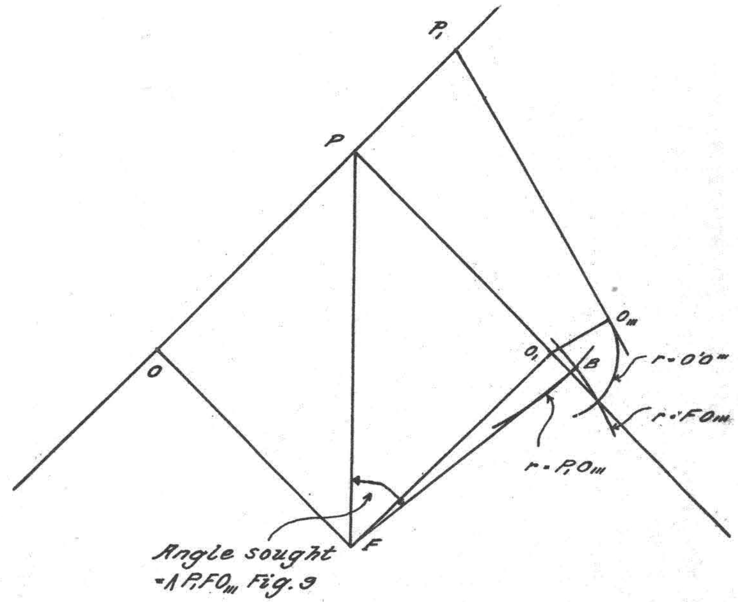

Fig. 12. –