ELEMENTARY ELEVATION DETERMINATION FROM AERIAL PHOTOGRAPHS

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WHEN a novice in the art of photogrammetry becomes fairly expert in the use of the simple stereoscope, it is only natural that a desire to take the next step forward arises. The intention of this article is to start off the novice photogrammetrist on the most interesting and certainly important phase of the use of aerial photographs. The determination of elevations from aerial photographs can become complex and deeply involved in the eventual attempt to achieve the ultimate in accuracy. However, to become capable of determining elevations precisely for map work of a high order of accuracy, the novice must begin at the beginning—and this article constitutes one good way of beginning. Furthermore, although the beginner may never aspire to stereoscopic elevation determination work of the highest order of accuracy, he can rather quickly become proficient at determining elevations to a lesser degree of accuracy for a multitude of highly important purposes.

This article will not attempt to explain the reason why certain procedures are followed or why certain formulae are used. No theoretical explanations will be given. It is possible for the beginner to learn quickly how to determine elevations without a thorough knowledge of the theoretical background. Naturally there is a point beyond which one cannot go without an understanding of the theory of stereoscopic measurements. When that time comes the novice can refer to the chapter of the Manual of Photogrammetry on the subject of "Stereoscopy" published in the July–August–September, 1942, issue of PHOTOGRAMMETRIC ENGINEERING or refer to the War Department publication, *Topographic Drafting*, T.M. 5–230.

SIMPLE EQUIPMENT

This article will deal only with the simplest form of stereoscopic equipment available for elevation determination. The novice cannot expect to learn how, over night, to operate the more complex stereoscopic plotting machines which are available for mapping from aerial photographs to a high order of accuracy. However, the fact that the plotting equipment discussed in this article is referred to as simple equipment does not mean to infer that the equipment cannot do valuable work; nor does it mean to infer that a person capable only of operating the simplest equipment cannot do very necessary and effective work. As a matter of fact the simple equipment described herein has several outstanding advantages.

a) The equipment, being simple, a novice can become rather proficient in its use for elevation determination within a period of only a few weeks.
b) The stereoscopic principles involved in this simple equipment are similar to those involved in the more elaborate plotting machines. Consequently, the simple plotting equipment can be utilized in the training of operators for the more elaborate instruments.
c) In a large percentage of cases where elevation determination is necessary, the degree of accuracy which can be tolerated is much lower than that which can be attained by the elaborate instruments. Consequently the simple devices become adequate and, in fact, economically desirable.
d) The low cost of the simple instruments together with the fact that new operators can be quickly trained makes it possible to put a large number of men and instruments to work on a given project to complete the project in a short period of time.

LIMITATIONS OF SIMPLE EQUIPMENT

A word of caution is necessary so that the novice will not become too enthusiastic over what can be accomplished with simple plotting devices. In the past, unfortunately, enthusiastic advocates of the simple plotting equipment have encouraged potential users of aerial photographs or of the simple plotting instruments to believe that a high order of accuracy can be attained. However, the exercise of common sense, completely disassociated from any photogrammetric knowledge, should be sufficient to convince anyone that simple plotting devices costing only a few hundred dollars at the most, have a far lower potential accuracy than the more elaborate plotting machines costing many thousands of dollars.

Actually, under optimum conditions and with a reasonably expert operator, and with good control available, spot elevations can be determined with the simple equipment to an order of accuracy of ±1/400th or 1/500th of the flight altitude. That is to say, for an airplane flying at 10,000 feet the accuracy to be expected under best possible conditions would be somewhere between ±25 feet and ±20 feet. When it is desired to actually sketch contours (more correctly called form lines) with the simple equipment, the possible accuracy under best conditions falls off to approximately ±1/250th of the flying altitude. Thus, for an airplane flying at 10,000 feet the accuracy of the form lines would be in the neighborhood of ±40 feet. As the conditions depart from the ideal with the introduction of tilt, tip and difference in elevation between successive photographs, the accuracy possible with the simple equipment drops rapidly below that mentioned.

It is also necessary to have a certain amount of ground control (points whose elevations have been determined by ground surveying methods) in each stereoscopic pair of photographs. The more control available, the greater will be the accuracy of the elevations determined with the simple plotting equipment and the more able will be the operator to compensate for tilt and other errors. Six well distributed control points throughout the area of overlap is considered a desirable minimum. However, when the situation demands, very effective elevation information can be gained with as little as one ground control point to start from.

EQUIPMENT REQUIRED

The elementary elevation measuring device is known as a simple "parallaxer." A "parallaxer" consists of four main parts (Fig. 1).

a) There must be a stereoscope to give a three dimensional view of the stereoscopic pair of photographs.
b) Either attached to the stereoscope or separate from it is a floating mark system.
c) There should be a drawing attachment which can be connected to the floating mark system when desired.
d) Whenever the drawing attachment is used, the floating mark-drawing attachment combination should be attached to a parallel motion protractor.

The floating mark system consists usually of two glass discs, each of which has a very minute dot in the center. Sometimes these floating marks are incorporated in the stereoscope itself, whereupon the assembly becomes known as the Stereo-Comparagraph, as shown in Figure 2. In another case the floating marks are made a part of a measuring bar which is called a Parallax Bar and which is independent of the stereoscope as shown in Figure 3. Actually the Parallax Bar is of no value by itself, but must be used in conjunction with a stereoscope as shown in Figure 3.

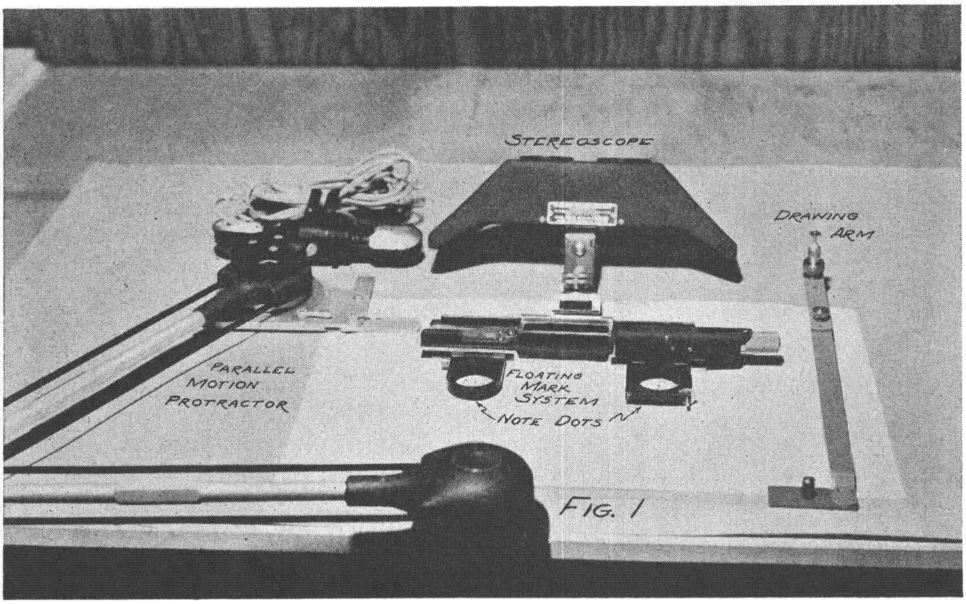

STEREOSCOPE
DRAWING ARM
PARALLEL MOTION PROTRACTOR
FLOATING MARK SYSTEM
NOTE DOTS

FIG. 1

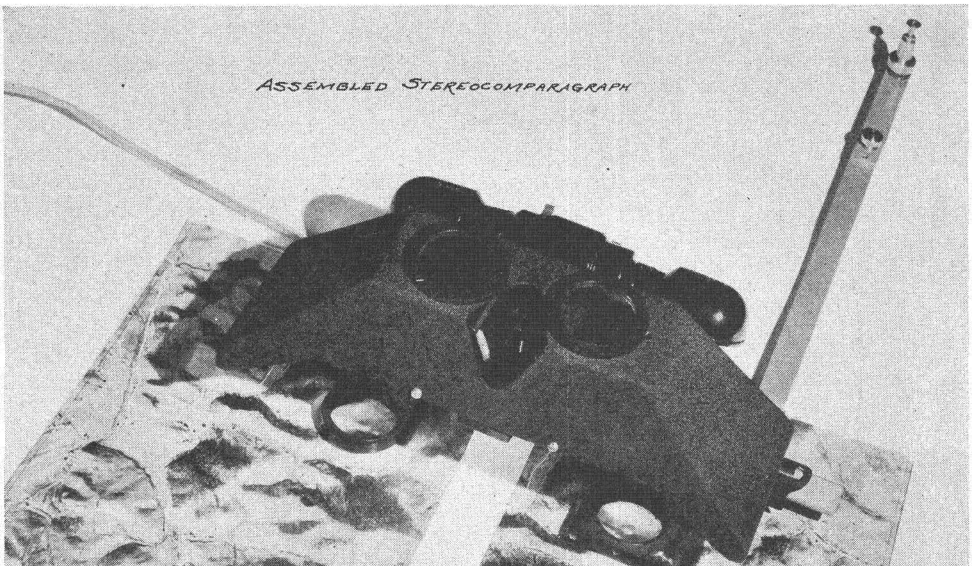
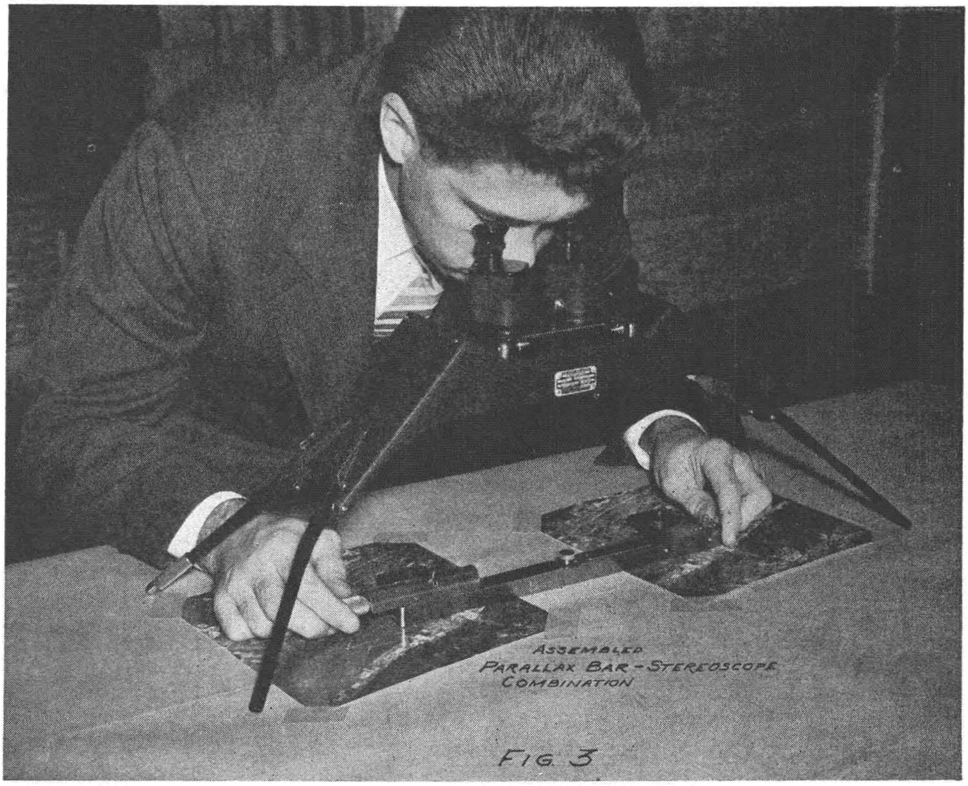

ASSEMBLED STEREOCOMPARAGRAPH

FIG. 2



ASSEMBLED
PARALLAX BAR - STEREOSCOPE
COMBINATION

FIG 3

The Stereo-Comparagraph is preferable where an instrument is needed continuously for the purpose of determining elevations or delineating form lines. The Parallax Bar is more desirable where the stereoscope is used primarily for visual inspection or interpretation of stereoscopic pairs of photographs and where only occasionally it is necessary to determine elevations or to delineate form lines. The accuracy and ease of operation of the two generalized types of equipment are essentially the same.

FLOATING MARK

Whether the simple plotting device is of the Stereo-Comparagraph type or of the Parallax-Bar-Stereoscope type, the determination of elevation is entirely dependent upon an understanding of, and ability to use the floating mark. The floating mark consists actually of two so-called "half" marks which were described above as being two circular or rectangular pieces of glass, each of which has a very fine dot at the center (Fig. 1). By the design of the Stereo-Comparagraph or by the design of the Parallax Bar, when the photographs are properly oriented and the stereoscope or Stereo-Comparagraph is in place for three dimensional viewing, the "half" marks are approximately lying on top of the same bit of image detail in each of the photographs. When the operator looks through the stereoscope or Stereo-Comparagraph, he sees only one dot. The reason he sees only one dot when actually there are two dots in the field of view of the stereoscope is the same as the reason for the fact that he only sees one photograph when he looks through the stereoscope at a pair of photographs. The one view which results from the pair of photographs is in three dimensions.

Likewise, the one dot that he sees which is the floating mark is also seen three dimensionally.

An important part of a Stereo-Comparagraph or of a Parallax Bar is the micrometer which moves the right hand half mark either toward or away from the left hand half mark. As this is done, the single floating mark which is seen by the operator looking through the stereoscope appears to rise up or to sink down in the field of view. The mark can be made to rise up to the point where it is resting on top of a hill, or it can be made to sink down until it lies in the bottom of a valley.

Generally speaking, to determine the difference in elevation between the hill top mentioned and the valley below, the operator causes the floating mark to rise up and to the best of his ability, come to rest on the top of the hill. The micrometer reading can then be noted. The operator then causes the floating mark to descend until, to the best of his ability, it appears to lie on the bottom of the valley. Again he reads the micrometer. The difference in micrometer readings can be found by subtraction and is called the parallax difference. With the value thus found, tables can be entered from which a knowledge of the difference in elevation between those two points can be determined.

The judgment as to whether or not the floating mark is lying exactly on the ground at any given point depends largely upon the operator's eyesight and experience. The micrometer which moves the right hand half mark can be read directly to hundredths of a millimeter and can be estimated to thousandths. After a few weeks' training, a novice should be able to read the parallax measurements on any given point in the stereoscopic view within ±.05 millimeters consistently. With prolonged experience, an operator with particularly good eyesight and stereoscopic judgment can reduce this to approximately ±.03 millimeters. Consequently, for the beginner, a good practice problem is to select six or eight points at various elevations and in various portions of the stereoscopic view and to measure the parallax of each one in succession. Go around the circuit several times marking the readings down independently and after the third or fourth time around, check to see how closely the parallax readings on each point agree with one another.

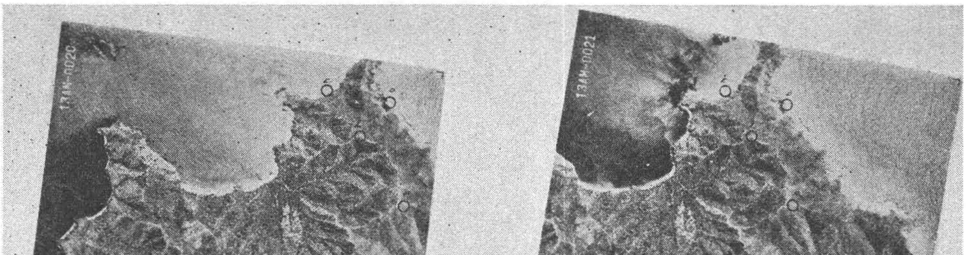


FIG. 4

PARALLAX TABLES

As mentioned previously the difference between the micrometer readings of two points in the stereoscopic view constitutes a measure of the difference in elevation. It does not give the elevation in terms of feet. It is necessary to convert the difference in micrometer readings which really is the difference in parallax over into difference in elevation. With certain known factors to begin with, formulae and computations can be resorted to in order to convert the parallax difference into difference of elevation as expressed in feet. However, where a lot of elevations are being determined it is slow and cumbersome to perform a computation each time.

For many years a book of tables known as "parallax tables" have been published by the British government and have been used. However, in recent years it has been impossible to obtain any of these parallax tables. Furthermore it was felt that the tables could, in the light of present day knowledge, be set up in a more simple form. Parallax tables are now available in this country and are incorporated in the War Department publication, *Topographic Drafting*, T.M. 5-230. Incidentally this particular publication is one of the most practical treatises on basic photogrammetric mapping available and every photogrammetrist should have a copy.

The compilation of parallax tables constitutes quite a problem because a number of factors have to be taken into consideration. Since these factors change according to the different conditions under which the photographs are taken, it becomes necessary to make certain assumptions. One assumption made in the parallax table is that the length of the stereoscopic base (symbol B_m) is 100 millimeters.

Point	*Elevation*	$(H-h)$	$\Sigma\Delta p$	Δp	$\Delta p \times \frac{B_m}{100}$	*Micrometer Reading*
			From "E" to "L"			
E	0	10,500 ft.	86.750 mm.			10.84 mm.*
L	433 ft.	10,067 ft.	90.958 mm.	4.21 mm.	2.35 mm.	13.19 mm.
			From "D" to "L"			
D	0	10,500 ft.	86.750 mm.			10.95 mm.*
L	413 ft.	10,087 ft.	90.760 ft.	4.01 mm.	2.24 mm.	13.19 mm.

Average Elevation of "L"—423′

* Should be identical except for observational, tip, tilt and altitude errors.

FIG. 5

For the purpose of this article the stereoscopic base can be considered as the distance from the principal point of one photograph to the transferred principal point in that same photograph as shown in Figure 4. It is quite unlikely that the stereoscopic base length of each photograph of the stereoscopic pair will be identical. Therefore the average stereoscopic base should be used. Actually, if one finds a photograph with a stereoscopic base of exactly 100 millimeters, it would be by strangest coincidence. However, the effect of change in length of stereoscopic base is one of direct proportion. Therefore, if one measures the stereoscopic base and finds it to be, let us say, 53.5 millimeters in length, each value of parallax shown in the table must have the ratio of 53.5/100 applied to it. This is a very easy and simple computation. The assumption of $B_m = 100$ millimeters upon which the parallax tables are based does not compromise the accuracy of the tables in any way.

PROCEDURES TO DETERMINE THE ELEVATION OF A POINT

The following is a step by step explanation of the procedure to determine the elevation of one or more points in the stereoscopic view.

A stereoscopic pair of photographs and the Stereoscope or the Stereo-Comparagraph should be set up in strict conformity to the instructions contained in an article in the October-November-December, 1942, issue of PHOTOGRAMMETRIC ENGINEERING, entitled "Orient Your Stereoscope Correctly."

As mentioned previously, there must be a certain number of points of known elevation in the stereoscopic view known as ground control points. The position of these points should be accurately marked on both photographs of the stereoscopic pair. These points can be marked by a fine pin prick surrounded by a circle of approximately ¼″ diameter (Fig. 4). For ease in keeping track of the data, the control points should be lettered consecutively and it is sometimes desirable to actually write on the photograph adjacent to the control point, the elevation of the point. In like manner the points concerning which it is desired to determine the elevation should be indicated with a pin prick surrounded by a circle. Likewise, these points, the elevation of which is to be determined, should be given an identifying letter as shown in Figure 4.

SAMPLE PROBLEM

Assume that it is desired to find the elevation of the hill top point *L* in Figure 4. Points *E* and *D* are at mean sea level and provide starting points from which the elevation of point *L* can be determined. Actually to get the best determination of elevation of point *L* a determination should be made based upon point *E* and then an independent determination made, based upon point *D*. If the two determinations do not agree exactly, which they probably will not, the average should be taken.

a) The first step is to measure the stereoscopic base length on each photograph of the stereoscopic pair. As mentioned previously, the stereoscopic base length on the two photographs of the pair will undoubtedly differ, which is the case in the actual problem under consideration here, where the average stereoscopic base length works out to be 55.85 mm.
b) The altitude of flight of the aircraft from which the photographs were taken must also be known. In this particular case, the altitude of flight was 10,500 feet above mean sea level.
c) The next step is to make up a form in which to insert the various data as shown in Figure 5. Fill in this table with all the known information concerning the points *D* and *E*. Inasmuch as the point *E* is at sea level, the elevation is obviously *o*. The quantity (*H-h*) must next be figured. *H* refers to the altitude of flight of the aircraft while *h* refers to the elevation of the point being dealt with at the time. Consequently for the point *E* we have (10,500–0) which leaves us 10,500 feet to insert in the (*H-h*) column.
d) It now becomes necessary to refer to the parallax table found in the War Department publication T.M. 5–230. On page 243 (see Figure 6) give your attention to the right hand set of three columns. In the column headed (*H–h*) find the value 10,500. Opposite that value and in the column headed $\Sigma\Delta p$ find the value 86.750 millimeters and insert this value in the form which has been prepared as shown in Figure 5.
e) The next step is to read the parallax of the point *E* by the use of the Stereo-Comparagraph or the Stereoscope and Parallax Bar combination. This is done by so moving the instrument and by so adjusting the micrometer that the floating mark appears to lie exactly on the ground at point *E*. This reading is found to be 10.84 millimeters and this value is inserted in the column headed "Micrometer Reading" in Figure 5. Actually the 10.84 millimeter value is not a single reading but is the average of four or five readings.

TOPOGRAPHIC DRAFTING
TM 5–230
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$(H-h)$ *ft.*	Δp *mm.*	$\Sigma\Delta p$ *mm.*	$(H-h)$ *ft.*	Δp *mm.*	$\Sigma\Delta p$ *mm.*	$(H-h)$ *ft.*	Δp *mm.*	$\Sigma\Delta p$ *mm.*
13000	0.154	65.392	11840	0.169	74.739	10680	0.187	85.050
12980	0.154	65.546	20	0.169	74.908	60	0.187	85.237
60	0.154	65.700	11800	0.169	75.077	40	0.188	85.425
40	0.154	65.855	11780	0.170	75.247	20	0.188	85.613
20	0.155	66.010	60	0.170	75.417	10600	0.188	85.802
12900	0.155	66.164	40	0.170	75.587	10580	0.189	85.991
12880	0.155	66.320	20	0.170	75.758	60	0.189	86.180
60	0.155	66.475	11700	0.171	75.928	40	0.190	86.369
40	0.156	66.631	11680	0.171	76.099	20	0.190	86.559
20	0.156	66.787	60	0.171	76.271	10500	0.190	86.750
12800	0.156	66.943	40	0.172	76.442	10480	0.191	86.940
12780	0.156	67.099	20	0.172	76.614	60	0.191	87.131
60	0.157	67.256	11600	0.172	76.787	40	0.191	87.323
40	0.157	67.413	11580	0.173	76.959	20	0.192	87.514
20	0.157	67.570	60	0.173	77.132	10400	0.192	87.707
12700	0.157	67.727	40	0.173	77.305	10380	0.192	87.899
12680	0.158	67.885	20	0.173	77.479	60	0.193	88.092
60	0.158	68.042	11500	0.174	77.652	40	0.193	88.285
40	0.158	68.201	11480	0.174	77.827	20	0.194	88.479
20	0.158	68.359	60	0.174	78.001	10300	0.194	88.673
12600	0.159	68.518	40	0.175	78.176	10280	0.194	88.867
12580	0.159	68.676	20	0.175	78.351	60	0.195	89.062
60	0.159	68.836	11400	0.175	78.526	40	0.195	89.257
40	0.159	68.995	11380	0.176	78.701	20	0.196	89.452
20	0.160	69.164	60	0.176	78.877	10200	0.196	89.648
12500	0.160	69.314	40	0.176	79.054	10180	0.196	89.845
12480	0.160	69.474	20	0.177	79.230	60	0.197	90.041
60	0.160	69.635	11300	0.177	79.407	40	0.197	90.238
40	0.161	69.796	11280	0.177	79.584	20	0.197	90.436
20	0.161	69.956	60	0.177	79.761	10100	0.198	90.634
12400	0.161	70.118	40	0.178	79.939	10080	0.198	90.832
12380	0.161	70.279	20	0.178	80.117	60	0.199	91.030
60	0.162	70.441	11200	0.178	80.296	40	0.199	91.229
40	0.162	70.603	11180	0.179	80.474	20	0.199	91.429
20	0.162	70.765	60	0.179	80.654	10000	0.200	91.629
12300	0.162	70.927	40	0.179	80.833	9990	0.100	91.729
12280	0.163	71.090	20	0.180	81.013	80	0.100	91.829
60	0.163	71.253	11100	0.180	81.193	70	0.100	91.929
40	0.163	71.416	11080	0.180	81.373	60	0.100	92.029
20	0.164	71.580	60	0.181	81.554	9950	0.100	92.130
12200	0.164	71.744	40	0.181	81.735	40	0.101	92.230
12180	0.164	71.908	20	0.181	81.916	30	0.101	92.331
60	0.164	72.072	11000	0.182	82.097	20	0.101	92.432
40	0.165	72.237	10980	0.182	82.280	10	0.101	92.533
20	0.165	72.402	60	0.182	82.462	9900	0.101	92.634
12100	0.165	72.567	40	0.183	82.645	9890	0.101	92.735
12080	0.165	72.732	20	0.183	82.828	80	0.101	92.836
60	0.166	72.898	10900	0.183	83.011	70	0.101	92.937
40	0.166	73.064	10880	0.184	83.194	60	0.101	93.038
20	0.166	73.230	60	0.184	83.378	50	0.101	93.140
12000	0.167	73.397	40	0.184	83.563	40	0.102	93.241
11980	0.167	73.563	20	0.185	83.747	30	0.102	93.343
60	0.167	73.730	10800	0.185	83.932	20	0.102	93.445
40	0.167	73.896	10780	0.185	84.118	10	0.102	93.547
20	0.168	74.065	60	0.186	84.304	9800	0.102	93.649
11900	0.168	74.233	40	0.186	84.490	9790	0.102	93.751
11880	0.168	74.402	20	0.186	84.676	80	0.102	93.853
60	0.168	74.570	10700	0.187	84.863	70	0.102	93.955

FIG. 6

f) The next step is to determine the parallax reading for the unknown point (point L in this case). This is done by causing the floating mark to rest exactly on the point L as in the case of point E previously. The resulting parallax measurement amounts in this case to 13.19 millimeters, which value is also the average of four or five different readings. This value is also inserted in the column under "Micrometer Readings" (Fig. 5).

g) The difference in parallax as found by the difference between the two micrometer readings mentioned immediately above amounts to 2.35 millimeters. This value is inserted in the column headed $\Delta px \frac{B_m}{100}$ in Figure 5.

h) It was explained previously that the parallax tables are based upon photographs having a stereoscopic base length of 100 millimeters. However, the difference in parallax of 2.35 millimeters just mentioned above is based upon measurements taken from photographs having an actual stereoscopic base length of 55.85 millimeters. In order to convert this parallax difference so that it will be on the same basis as the tables, a proportion must be worked out as follows:

$$2.35 \text{ mm.}: 55.85 = X:100$$

X in this case is actually Δp on the basis of the tables and works out to be 4.21 millimeters. This value, 4.21, is then inserted in the column Δp (Fig. 5).

i) By inspection of the stereoscopic view, it can be seen that point L is higher than point E. Therefore, the value of 4.21 millimeters in the Δp column is added to the value 86.750 millimeters in the $\Sigma\Delta p$ column for point E to obtain a $\Sigma\Delta p$ value for point L of 90.958 millimeters which is inserted in its proper place (Fig. 5).

j) Refer again to the parallax tables, page 243 of T.M. 5–230 (Fig. 6) and under the column headed $\Sigma\Delta p$ look for the value closest to 90.958 millimeters. This value can be seen to lie somewhere between 10,080 feet and 10,060 feet. By a process of interpolation such as is commonly resorted to in work with logarithms, it is found that the value of $(H-h)$ for a $\Sigma\Delta p$ of 90.958 is 10,067 feet. This value is inserted in its proper place in the form as shown in Figure 5.

k) There now exists the equation $(H-h) = 10,067$ feet. It is known that H is the altitude of flight of the aircraft, namely 10,500 feet. Therefore h solves out to equal 433 feet. This is inserted in the elevation column opposite point L (Fig. 5). Thus the elevation of point L when computed from point E is 433 feet above sea level.

l) Since point D is equally close to point L and can be used as a control point, it is desirable to run through the above described computation, but working from point D instead of from point E. Fig. 5 shows the computation involved. It can be seen that the elevation of point L works out to be 413 feet in this case. The reason for the discrepancy between the two determinations of the elevation of point L can be due to many factors among which the most important are the presence of tilt and difference in elevation between successive photographs. The two values averaged give an elevation for point L of 423 feet.

Situations may arise where neither parallax bars nor stereo-comparagraphs are available. The lack of these instruments hampers elevation determination but does not preclude it for the ingenious photogrammetrist. With the photographs oriented and mounted as explained in the October-November-December, 1942, issue of PHOTOGRAMMETRIC ENGINEERING ("Orient Your Stereoscope Correctly") much can be accomplished in the way of elevation determinations with a finely divided scale. A millimeter scale is preferable but an English scale can be used provided the values determined are converted into metric units.

The procedure consists of measuring the distance from a control point on the left hand photograph to the same control point where it appears in the right hand photograph. The scale should be read with great care using a high power magnifying glass and recorded. The same procedure should be followed with respect to the point whose elevation is to be determined. The difference between the two distances is the parallax difference of the two points. With this value known, the computational and tabular procedure outlined above can be resorted to for the elevation of the point.

At best, this expedient results in considerably lower accuracy than that possible with the stereo-comparagraph or parallax bar.

General Remarks

The same procedure as explained above can be used in any part of the photograph where reference can be made to actual ground control points. The closer the point to be determined is to ground control, the higher will be the accuracy of the determination; and conversely, the farther away the point is from ground control the more error will be introduced into the determination. It should always be attempted to determine important elevations with reference to two or more control points if available. In averaging the result, a good approximation is to give the greatest weight to the determination as derived from the nearest control point if the linear distances to the control points are not approximately equal.

CONTROL POINT DATA FOR GRAPH CONSTRUCTION

Point	*Elevation*	*Parallax*
C	1,013 ft.	14.70 mm.
E	0	10.84 mm.

FORM LINE DATA TAKEN FROM GRAPH

Elevation	*Parallax*
0	10.84 mm.
50	11:03
100	11.22
150	11.41
200	11.60
250	11.79
300	11.99
350	12.18
etc.	etc.

Fig. 7

Contouring a Stereoscopic Pair of Photographs

The term "contour" is frequently used rather loosely in connection with stereoscopic plotting with simple parallax devices. A contour is a line on a map joining points of equal elevation. The contours on some maps are more accurately placed than those on other maps. However, the term contour can be used so long as the degree of accuracy of the location of the contour is the same throughout the map regardless of whether the accuracy be high or low. When the degree of accuracy of the position of the contour is not consistent but varies in different portions of the map, the line cannot be called a contour but should be referred to as a form line.

In the previous description of the procedure of determining the elevation of a given point, only one point was considered, namely the point *L*. However, if a person so desires, the elevation of a great number of points in the stereoscopic view can be determined in the same way. These points, for example, should be located along the ridges of all the various hills showing in the area of overlap and also along the valleys and also at all points where the general slope of the land changes. In a stereoscopic view showing very gently rolling land, not a great number of spot elevations are required. In very rough terrain, hundreds of points might be required along the ridge lines, valleys and breaks in slope. However, if the large number of points required are all very carefully determined as explained in the foregoing procedure, a topographic map can be made in which the lines joining points of equal elevation can be termed contour lines. These contour lines can be plotted by the usual mapping procedure of interpolating the contours between points of known elevation.

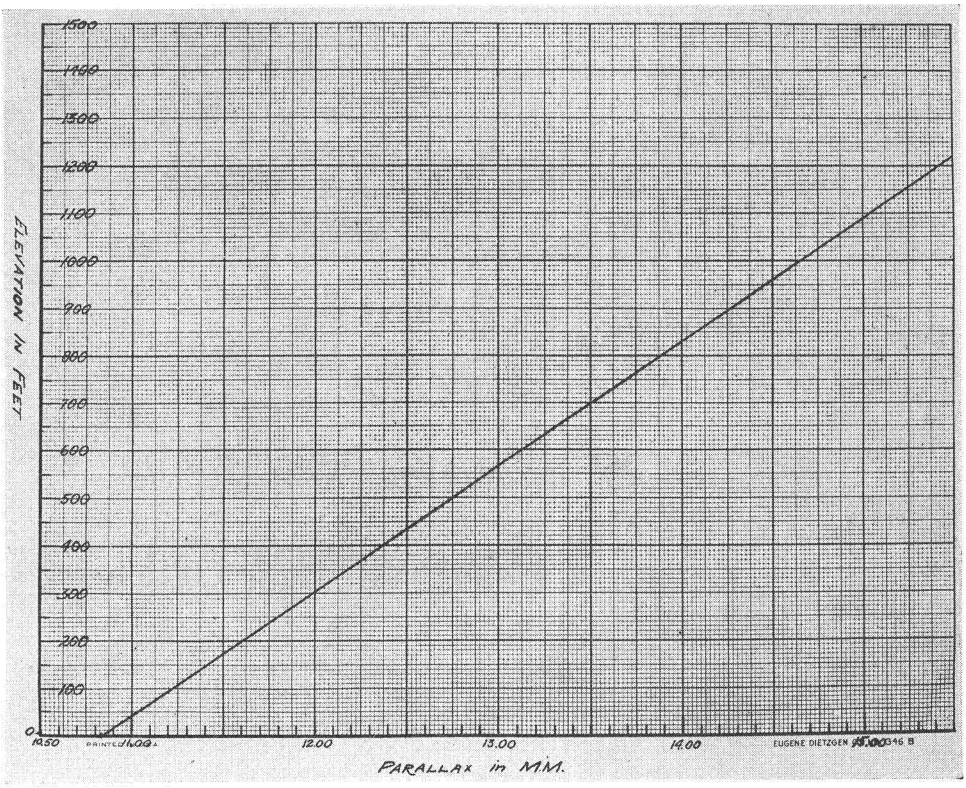

FIG. 8

FORM LINES

The determination of contour lines according to the procedure briefly mentioned above is exceedingly long and tedious. It is much faster and easier, although less accurate, to use the Stereo-Comparagraph or the Parallax Bar as a sketching device to draw form lines in a continuous fashion.

The drawing of form lines can be based on any number of control points from one on up. As a matter of fact, under conditions of absolute necessity, some success can be attained even in the face of the complete lack of ground surveyed control points. In that case, the best possible guess or estimate is made of the elevation of some one point in the stereoscopic view and that elevation becomes a control point from then on. Where the operator is so fortunate as to have a bit of shore line showing in the stereoscopic view, the estimation of the sea-level zero elevation will be reasonably accurate. The estimation of inland elevations is apt to be considerably in error and any elevation determined from such points will likewise be in error proportionately. However, the intent of form lines is not to show relative elevation but to show the form of the hills and valleys for the many uses which can be made of such information.

If only one control point is known, the elevation of some other point in the stereoscopic view, either considerably higher than the control point or considerably lower, should be determined by the method explained previously. (See Fig. 5.) The second point, whose elevation thus becomes known, can be considered as a second control point.

A table can be made up, such as the one shown in Figure 7 giving the elevations of the two control points *E* and *C* (Fig. 4) and the parallax readings obtained from the Stereo-Comparagraph or from the Parallax Bar on those points. After having tabulated in the table (Fig. 7) the elevations and parallax readings of the two control points, a graph can be made as shown in Figure 8.

The vertical axis of the graph can be the elevation axis, whereas the horizontal axis of the graph can be the parallax axis. Scales should be selected for the graduations which will make it possible to read the elevation and parallax to the desired accuracy. It is important that the parallax axis be so graduated to permit the parallax to be plotted to .01 millimeters.

Knowing the elevations of the two control points, the operator can, by studying the stereoscopic view, estimate roughly the range of elevation from highest to lowest in the stereogram. This obviously gives the extent of the elevation axis of the graph which has to be plotted.

The form line interval to be used is found by dividing the altitude of flight of the aircraft by a value ranging between 200 and 300. Where control is at a minimum and where serious tilt is likely to be present in the aerial photographs, the altitude should be divided by not more than 200. As the amount of control increases and the general conditions of the work improve, a greater divisor can be used. However, in the example shown in Figure 8 the 200 figure is used which gives the nearest even form line interval to be 50 feet.

Plot the elevation of the two control points with respect to the parallax values in the conventional manner as shown in Figure 8. Draw a straight line through the two points to complete the graph. Actually the parallax curve as the resulting straight line is called, should be slightly curved. However, the curve is so slight and the possibilities for considerable errors in form line work are so great that the difference between the curve and the straight line would not appreciably effect the result. If more than two control points are available, they should also be plotted in the same manner. In that case it is likely to be found that the three or more points will not lie in the same straight line, due to errors of observation, errors due to tip and tilt of the photographs and errors due to difference in elevation between the succeeding photographs. In that case, the straight line should follow an average path through the plotted control points.

With the graph now completed, the table in Figure 7 can likewise be completed by reading off from the graph the parallax readings for each 50 foot form line.

For form lining, the Stereo-Comparagraph or the Parallax Bar should be attached to a Parallel Motion Protractor and should have a drawing attachment in place.

A sheet of paper of suitable size should be affixed to the drawing table so that when the Stereo-Comparagraph or Parallax Bar is moved to any portion of the photograph to be viewed, the pencil will still be on the drawing paper. With the operator looking through the stereoscope of the plotting device, whether it be Stereo-Comparagraph or Parallax Bar, the road system, shore line, rivers, streams, lakes and all other features of a similar nature should be drawn first. This is done most conveniently by turning up the right hand floating mark assembly of the Stereo-Comparagraph. When looking through the Stereo-Comparagraph the remaining mark appears always in contact with the ground regardless of the apparent depth of the three-dimensional image. The operator can then cause the mark to move along the roads, streams, fence lines, etc., while the pencil attachment delineates the features traced. In the case of the parallax bar where the floating marks cannot be lifted up, the left hand mark can be removed completely for the tracing of planimetry.

After all the features mentioned above have been drawn in, the form lining can begin. If the parallax bar or Stereo-Comparagraph is in the planimetry tracing condition (only one mark in place) the instrument must be restored to its normal condition with both half marks in position. It is customary to start by drawing the lowest form line. Scan the area for what appears to be the lowest point and cause the floating mark to rest on that point. Read the micrometer, thereby obtaining the parallax measurement of that point. Look in the table (Fig. 7) for the next highest value of parallax which corresponds to an even 50 foot form line elevation. Then adjust the micrometer of the instrument to read the value of parallax of that form line elevation. By means of the small locking lever provided, the micrometer can be locked so that it cannot accidentally be changed due to an accidental brushing of the hand against the micrometer, or other cause. With the micrometer locked at that particular setting, the operator moves the instrument throughout the stereoscopic view wherever it can be moved, always maintaining the floating mark in contact with the ground. This will result in a line starting at one edge of the photograph and proceeding by an irregular course to some other edge of the drawing paper, or will result in a line starting somewhere within the drawing area and after proceeding along an irregular course, closing the figure by coming back to the starting point. After all parts of the photograph have been covered for that one form line, the operator can refer to the table in Figure 7 for the setting which must be set on the micrometer for the next highest 50 foot form line elevation. The micrometer is then adjusted to that value and the same procedure is followed. Eventually the sketch drawn by the pencil attachment takes on the appearance of a topographic map with the form lines superimposed over the highway and drainage features.

Other pairs of photographs can be form lined in a similar fashion. The several perspective sketches resulting can be reduced and combined by a radial line plot, pantagraph, or projector to give a form line map of a larger area than that shown in any one stereoscopic view.

CONCLUSION

Many refinements can be resorted to, to improve the accuracy of stereoscopic elevation measurements. These refinements are omitted from this article purposely to avoid confusing the beginner. The refinements will be discussed in a later issue of PHOTOGRAMMETRIC ENGINEERING and will be rather easily understood after the student has attempted and mastered the simple fundamental procedure outlined herein.