conservation of natural resources, and flood control are on a sound basis. It would seem perfectly obvious that such programs must be dependent upon the fullest knowledge of the condition of the land and the natural resources dependent thereon. Not only are such maps essential to land utilization and conservation work but also they will repay their cost many times over in direct benefit to the owners of land, all users of land, taxing bodies, engineers and all persons or organizations whose work in any way relates or is dependent upon a knowledge of what actually exists in any land area.

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REMARKS ON THE DEVELOPMENT OF AIR CAMERAS FOR PHOTOGRAMMETRIC PURPOSES

by

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(Followed by Discussion by Lieutenant O. S. Reading)

From a perusal of the various articles composing the highly interesting May and June number of the "News Notes of the American Society of Photogrammetry" it is evident how wide a use is today being made in the United States of America of air photographs for the construction of topographical maps. The air-photographic method is employed chiefly in the case of large regions of which there exist as yet either no maps at all, or only very defective and out-of-date ones. In such cases the principal factor to be considered is that of speed, and it is thanks to photogrammetry that serviceable maps and plans can now everywhere be made in a very limited time. When speed is the main object, the means employed are relatively simple, but there is no mistaking the continual striving after improvement in the apparatus employed. Out of the simple stereoscope, giving only small-sized images, there has developed an improved instrument with optical magnification, which, as its name of "contour-finder" implies, is useful in topographical mapping from photographs. For the taking of measurements from oblique photographs a photogoniometer has been devised, and a mechanical plotter for monocular vision has been constructed, the results obtained from which in practice have been such as to give rise to the hope that a stereo-apparatus, much simpler in design than the stereo-autograph hitherto in use might be designed on the same principle. Much as this is to be desired, however, it has to be borne in mind that the refinements and improvements which are continually necessary in the development of a piece of apparatus often lead eventually to considerable complications. Hence while the results of such studies may be looked forward to with the greatest interest, it will be well not to entertain too high hopes from them. With almost every kind of apparatus for map-making from photographs, the theoretical principle involved is quite simple; the difficulties only begin when it is sought to design a working apparatus embodying the principle.

As regards the manner of representing the ground on topographical plans, it is realized that with simple line drawing very many of the details that appear on the photographs are lost, and it is considered that in the future it is probable that the photographic representation may be retained, only with contour lines added. Modern methods of reproduction would permit of such maps being reproduced without difficulty.

There is, of course, much to be said for this idea, for the photographs always show a very large number of details which must be lost in making the line drawing. But a number of difficulties, some of which are insurmountable, oppose themselves to the exclusive employment of the photographic picture in place of the line plan.

One great difficulty arises from the fact that the photographic picture is a central projection, while the map is a parallel projection, of the terrain, considered as reduced in size. The two projections can only be identical when the land is flat and the axis of the central projection is parallel to the projection-direction of the parallel projection. And as this latter direction is vertical in space, the axis of the central projection, that is, the optic axis of the

photographic camera, must also be vertical. If this is not the case, then the photographic picture first obtained can be transformed by simple photography into another picture, such as would have been obtained had the camera-axis been vertical. But this can only be done for completely flat country, the surface of which need not however be horizontal. Elevations and depressions of every kind give rise to errors in the plan; and these errors will be the greater, the further the elevations and depressions are distant from the vertical line passing through the camera. At the point where this vertical line intersects the ground, the so-called nadir-point, differences of elevation have no effect on the plan. The errors on the plan manifest themselves in the following manner. For any single point of the terrain, the displacement in height causes a displacement on the plan in a direction towards or away from the nadir-point, which latter displacement will be the greater, the further one goes from the nadir. For any finite area, this displacement produces a distortion of shape on the plan.

These errors can be lessened if in the photographic transformation use is made, not of a single projection-plane, but of a series of different projection-planes, and the picture thus rectified in a series of steps instead of at a single operation, each step corresponding to a different projection-plane, but all the projection-planes being horizontal and therefore parallel to one another. The heights for these planes will naturally be chosen in accordance with the variations in height of the terrain. In this way we have theoretically in our hands the means of attaining any required degree of accuracy in the plan. But in practice the number of different projection-planes chosen must be limited, because to make many different settings is very time-consuming, and the correlation of the different partial pictures is difficult and soon becomes uneconomical.

Since the errors in plan increase the further one goes from the nadir-point, a given tract of hilly terrain requires, for a given degree of accuracy of result, the use of a larger number of different projection-planes for the photographic transformation, the larger the area photographed on a single plate. The phrase "the larger the area" requires, however, to be taken in a particular sense. A good deal depends on the way in which the larger area is secured photographically. The generalization only holds good when it is a question of making use of a smaller or larger portion of a given photograph, that is to say, when we use a smaller or larger angular extent of the photographic field. If however with a camera having a given angular width of field we secure a larger area of ground in the picture by taking a new photograph from a greater height above the ground, then, supposing the irregularities of the ground to be everywhere the same, the errors of the peripheral parts of the new picture will be the same as they previously were for the peripheral parts of the old picture, which now lie much nearer to the center; apart, that is, from any falling-off in the accuracy with which measurements can be made owing to the smaller scale of the new picture and possibly to inferiority in its quality due to its having been taken from a greater height. The nadir-distance should therefore in general not be regarded as a <u>linear</u> distance, but as an <u>angular</u> one, and should be expressed in angular measure with reference to the nadir-direction. In other words, the transformation will be the more accurate, the smaller the angular width of photographic field employed.

The map will only be satisfactory when instead of the single-photograph process we employ pairs of photographs. But then a reproduction of the photographic picture is out of the question, and drawing becomes the only possible method of representation.

A second difficulty about making exclusive use of the photographic picture for the representation of the terrain arises when the plans are to be used as a basis for engineering projects, or for any other purpose where lines of any kind will have subsequently to be drawn on them. There is no blank place left on the paper, and though the infinitude of small details enable the map to convey a complete picture of the ground, yet they overcloud the map in such a way as to unfit it for receiving additional drawing-work. It has to be borne in mind that besides the

photographic representation of the ground, contour lines will have been drawn in, and spot-heights, place-names, etc., will have been added.

When one draws a map from a photograph, one usually makes use of a stereoscope. The stereoscopic viewing of the picture greatly facilitates the recognition of details. In the stereoscope one readily distinguishes a hedge from a path, or from a ditch, and can draw in the detail correctly on the map. If on the other hand one has only the photographic plan, there is much more uncertainty than one would at first suppose.

The photo-plan can certainly not take the place of a good scientifically-drawn map; but on the other hand it can supplement it in a remarkable manner.

We have seen that a plan drawn from a single photograph or a photo-plan will be the more accurate, the smaller the angular width of field of the camera employed. The limits of the angular field are given by the accuracy required in the map and by the inequalities in height of the ground. By choosing suitable scales, making the necessary calculations, and using special apparatus (goniometers, mechanical plotters), one can, indeed, also obtain approximate results by the single-photograph process, even from decidedly oblique photographs; but then photographic transformation is out of the question.

The making of plans from oblique photographs always demands great care. In all cases one must be well informed as to the character of the terrain before one can decide to arrange oblique photographs in systematic order. The principal requirement for oblique photographs is open country, but little wooded and with but small inequalities of height. Nevertheless there may be exceptional cases where one may decide to take oblique photographs covering the steep flanks of mountains for the making of large-scale maps. The principal drawback of oblique photographs is that hill-ranges one behind another may obscure each other coulisse-fashion, giving rise to blanks in the resulting map.

The wider the angle of a vertical photograph, the more its peripheral parts take on the character of oblique photographs, with all their drawbacks.

In the construction of wide-angle cameras one should therefore give great attention to this point.

The advantages of wide-angle photographs are, of course, obvious. For the covering of a given area of ground one requires the fewer plates, the larger the angle; the area F included in a single photograph increases, in fact, in proportion to the square of the tangent of half the aperture-angle a. The principal advantage lies, however, not merely in the smaller number of photographs required, but in the consequent lessening of the number of control-points necessary for the mapping. The fixing of control-points is a task which always consumes time, and the shorter this time can be made, the greater is the advantage of the procedure. In systematically photographing a flat tract from a given height, only half as many control-points will be required with a camera of aperture 68° as with one of 50°. It is therefore easily comprehensible why it is sought to achieve wider and wider apertures. For a long time past endeavors have been made to increase the total angle by coupling together several single cameras. But from several single cameras one obtains several separate photographs, not a single wide-angled picture. To obtain this latter one must transform the single pictures photographically; and for that to be properly done, not only must the relative positions of all the single cameras be accurately known, but these positions must be equally accurately reproduced in the transforming-apparatus. By the use of special apparatus, photographic transformation can under certain circumstances be dispensed with. The accurate retention of the relative orientations of the single pictures is however as necessary as it is difficult. If the relative orientation is doubtful, the obtaining of a satisfactory map requires just as many control-points for each separate picture as would have been necessary had it been taken independently of the others. As can be seen from the description of the nine-lens camera of the Coast and Geodetic Survey, the use on such a multiple camera is a very complicated matter, the large

dimensions especially being liable to give rise to difficulty. We admire the eight large metallic mirrors which absorb only 15 to 20 percent of the light. It does not however seem very probable that a satisfactory plane surface can be obtained by the aid of correction-screws. Besides these difficulties, there is the question as to whether the construction and use of so gigantic a camera is justified, especially in regard to the results which are to be expected from it. Think of the camera weighing 300 pounds and making use of film almost two feet wide; of the crinkling of the film and the difficulties in development and photographic transformation; and of the space required for accommodation. What will be the quality of the resulting picture? That is difficult to say, but it will certainly be better in the middle than at the edges. The peripheral parts will in every case have completely the character of oblique views, and consequently all their drawbacks. It is not at all astonishing that on account of lack of detail in the four rectified pictures that were obtained from it, the photographic survey carried out with a five-lens camera for the Tennessee Valley Authority should have had afterwards to be repeated with a single camera. It is probable that the cause of this lay less in any defect of the original photographs themselves, than in the obscuring of detail in the outer parts of the landscape by forest trees. That was with the five-lens camera. With the nine-lens camera the defect would have been still more marked. In afforested or mountainous country the multiple camera therefore does not commend itself, except for mapping on small scales, when only the larger features of the ground are required to be shown.

In series-photographs with 60 percent overlap, the stereoscopic parallax will be the larger, the wider the angle of the camera. With increasing parallax there is also an increase in the precision with which heights can be determined, but only within certain limits. The greater the parallax, the more do the two views of the same object differ from each other, until finally no stereoscopic image of it can be formed at all. If the east side of a house is seen in one photograph, and the west side of it in the other, no stereoscopic image of the house is obtainable, except at most one of its roof. This will be evident on trying the following experiment. Hold a piece of paper with its nearest edge vertical and about 20 centimeters in front of the face, in such a way that one side of the sheet is seen by the left eye and the other by the right eye on alternately closing first one eye and then the other. On viewing the paper with both eyes, no stereoscopic effect is obtained; the spatial relationship of the paper cannot be grasped, at most its nearer edge being seen, and that only when it has not been quite neatly cut.

The same holds also for objects in the landscape; and on this account the base-ratio, that is, the ratio of the distance apart of two air-photographs, taken for the purpose of forming a stereoscopic picture, to the flying-height, is made not greater than 1:1-1/2 for flat open country and 1:3 for mountainous tracts. In pairs of terrestrial photographs the ratio of base to useful distance is even less, not exceeding 1:4. If a 60 percent overlap were aimed at with the nine-lens camera, which has an angular width of field of 130°, the base-ratio would work out at 12:7, which would often result in no stereoscopic effect at all being obtained. The two lower figures on page 6 of the publication to which I have referred above are therefore only of theoretical significance.

It is true that in exact mapping from stereoscopic pairs with accurate apparatus, neither differences of height nor inclination of the camera influence the precision to any very great extent. But with inclined photographs it is impossible to avoid gaps being left, and many details are obscured. The more open the country, the better the resulting map.

But how do things stand in regard to stereoscopic mapping from photographs taken with a multiple camera? The matter is obviously only one of interest when the complete picture derived from one exposure is combined with the complete picture derived from the next exposure. It is then assumed that the complete picture from each exposure can be satisfactorily made from the individual pictures that go to compose it. The precision-requirements for achieving this are, however, extraordinarily high. If multiple-lens cameras corresponding to those

used for the taking of the photographs are used in the stereoscopic apparatus, the problem of placing all the individual photographs in the same relative positions as they occupied in the camera with which they were taken presents such great difficulty as to be insoluble, except by methods which would be too inconvenient and too laborious in actual practice. If on the other hand the individual pictures obtained at each exposure are rectified and brought together on a single plate, the rectification itself imposes demands of a very high order. The complete picture can then be used with a single camera of longer focus, but the relative positions in space of two such complete pictures must be calculated before they can be utilized. The process is only suitable for mapping on very small scales.

The manifold difficulties and complications mentioned above as arising in the use of multiple cameras indicate that the solution of the problem should be sought for in another direction. From what has been said it will have become evident that there is no object in widening the angle of field too greatly. It must be conceded that angles of 50° for extended photogrammetric surveys from the air involve a relatively large number of exposures, and therefore also a relatively large number of control-points, unless the series-connection of the different photographs is utilized in some way. But also for series-connection a larger angle would be desirable, though it ought not to have to be achieved by the round-about way of multiple cameras.

Quite lately it has been proved that air-camera objectives can be constructed with a much larger aperture-angle than any of the objectives heretofore used in cameras for survey purposes, without having to sacrifice any of the requirements as to freedom from distortion. Herein, it would seem, lies the correct path to sound further development. It is now certain that distortion-free objectives of 90° aperture-angle can be made, with which the area that can be covered is four times as great as with objectives of 50° angle. From what has been said above, it is not worth while to attempt to extend this new limit very greatly.

Of course the apparatus for mapping from air-photographs will be made capable of utilizing the wider angle, and will then present advantages hitherto undreamed of in regard to cheapening and simplifying the processes of air-photogrammetry. That will be true for mapping from single photographs as well as for air-triangulation, for very exact mapping as well as for the rapid preparation of general plans in which a lesser degree of accuracy is required.

In offering these remarks, I do not seek in the least to belittle the great value of the publication to which I have referred, but rather to emphasize that value. For we must all be grateful to the authors of all these valuable contributions for providing us with a basis for further discussion and research, and thus contributing in a high degree to the further development and clarification of the most important photogrammetric problems of the present day. I cannot conclude without expressing my thanks to the American Society of Photogrammetry for their extremely interesting and stimulating publication.

DISCUSSION OF MR. BERCHTOLD'S PAPER BY LIEUTENANT O. S. READING

Mr. Berchtold deserves the thanks of the American Society of Photogrammetry for his very interesting discussion of the May-June 1935 "News Notes." Everyone echoes Burns' sentiment, "O, wad some power the giftie gie us To see ourselves as ithers see us," and Mr. Berchtold has very kindly complied. Every student of photogrammetry will do well to weigh and consider carefully each statement of his remarks, for they represent the viewpoint of one of the leading men of one of the leading instrument concerns of the world, the Wild Surveying Instruments and Supply Company of Switzerland. Insofar as his remarks are interpolated between his experience, they are entirely sound and very accurately represent the facts. Thus his discussion of the relative advantages of photo mosaic and line maps and of the difficulties of obtaining a reasonably accurate scale in specially ratioed mosaics of terrain having much relief is quite correct.