

Geographical Reconnaissance by Aeroplane Photography, with Special Reference to the Work Done on the Palestine Front

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H. Hamshaw Thomas was introduced by the society president with the following: "The lecturer this evening, Captain [Hugh] Hamshaw Thomas, was, before the war, more closely connected with the earth than with the air: a lecturer in Botany, and Fellow of Downing College, Cambridge. When the war broke out he joined the Air Force and has done some interesting reconnaissance work in Palestine. He will this evening give us the results of his experiences as to air photography."



The development of aerial photography during the War resulted in a system by which the results of a rapid reconnaissance of a large tract of country could be expressed in a graphical form. Such results become of geographical interest when it is possible to convert them into maps or charts, and consequently we have to consider both the methods of obtaining suitable photographic information over a wide area and the work of compiling from it reconnaissance maps of the area.

The subject under consideration is allied to the question of mapmaking from aeroplane photographs, but it is on a different footing, for our underlying idea is the execution of a general reconnaissance survey of a region leading to the construction of the best possible map on a scale of about 1 inch to the mile, or perhaps 1:40,000. Our methods must be rapid and easy, and will consequently differ from those employed with the object of mapping every feature of the surface of the ground in its exactly correct position. If we wish to deal with local features such as towns or ruins on a

more detailed scale, we shall have to be content with relative accuracy of position in the locality, but in our small-scale maps we shall aim at a degree of accuracy which is not much less than that usually attained in such productions.

It will be convenient to divide the materials to be brought forward into two classes, under the following headings. (A) The experience gained on the Palestine Front, where the author was employed during the latter half of the war. (B) The examination of the methods employed in this region and the consideration of their applicability to other areas.

The methods of mapping from aeroplane photographs on the Western Front have been already described by Colonel MacLeod (*Geographical Journal*, 53: 382, June 1919), and it will be seen that those which are here described are considerably different. The methods developed in the East were quite independently worked out and are based on the taking of special photographs in a particular way, rather than on the utilization of any photographic material which the Air Force could obtain. It may be useful, therefore, to notice at the outset some of the causes which contributed to this divergence of method. In the first place, the conditions of aerial activity in France were very unfavourable for mapping photography. Straight flying and the production of long series of photographs were virtually impossible. On the other hand, the Palestine system postulated the unhampered activity of the airman and the close co-operation of the personnel of the Air Force and Survey Company. Again in the East the area to be photographed by a single Air Force unit was much greater than in the West, and economy in time, aircraft, and material had to be closely studied; and this encouraged the employment of methods which were perhaps somewhat less refined. In the East, also, the accuracy of position which was possible in the final maps was never so great as that achieved or required on the Western Front, but the shape of the ground was of the utmost importance. It is not therefore surprising that the two systems as finally established showed many points of difference. It is unwise to conclude that one system is better than the other, while the assumption that the system employed on the Western Front is naturally the better for future use, is unwarranted.

Aerial Survey in Sinai and Palestine

A. Development of a Method

The possibility of using aeroplane photographs in the production of maps was investigated in Egypt during 1915 under the direction of Mr. E. M. Dowson, at that time Director of the Survey of Egypt, and the results obtained were utilized in connection with the operations in Gallipoli. The underlying principles of the work, together with the difficulties to be met and the precautions to be taken, were made clear in these investigations, which may be regarded as the foundation of the system used in the East.

During 1916 some small amount of work was carried out in the Suez Canal zone, but during the advance of the army into Sinai the method fell into abeyance. In Sinai the existing maps were not sufficiently detailed to allow of the location of the photographs taken, and it was seldom that photo-groups could be scaled from the map. Moreover, the

advance of our troops was rapid and the need for detailed maps was not greatly felt. During this period, however, some work was done in the production of photo-mosaics of selected areas, and valuable lessons were learned from these. It was found that photographs which were intended to be truly vertical were often considerably distorted owing to the optical axis of the camera being tilted at the moment of exposure. On the other hand, it appeared that if the camera was rigidly mounted on the machine and carefully levelled, and if the pilot was flying on a straight course, the distortion was much less. Better results were obtained by covering an area by a series of strips of consecutive photographs than could be got by the practice of taking separate views of a number of adjacent points in no regular order (often known as pin-pointing). This led to the initiation of the strip system.

By the end of 1916 a considerable advance had been made. A good town map of Gaza was produced from a series of parallel strips of photographs, and a MS [military survey] sketch-map of Rafa, produced from intersecting strips, was very useful in the battle at that place. The lack of points on the map which could be identified on the photographs led to the taking of several long series of 50 to 70 overlapping exposures which were invaluable for placing subsequent prints or series.

When the Turks made a stand on the Gaza-Beersheba line and commenced to dig systems of trenches, mapping by aerial photography became of great importance. The pre-war maps were quite inadequate for trench warfare, and a new series of maps on scales of 1:40,000 and 1:20,000 had to be constructed, sometimes entirely from photographic material. The whole area occupied by the enemy's troops and a considerable extent of country to his rear, especially along the roads and railways, was photographed. The photographs were taken in intersecting series, some along the front, some extending from our lines into the enemy's territory, and these were built up into maps upon a meagre framework of points fixed in our lines, or located by intersections from our territory. A few points were furnished by the older maps, but these had to be used with caution. The results were on the whole successful and were very favourably received, valuable lessons were learned, and confidence was gained by all concerned in the map production. Some 400 square miles of country were mapped from photographs, and since during much of the period the German aviators had markedly superior machines, our progress owed much to the skill and daring of our R. F. C. pilots. By October 1917 a system of photography and map compilation had been arrived at, which held in essentials to the end of the war.

This historical summary has been given in order that it may be understood how the work in Palestine commenced. The need for maps on a scale of about 1:40,000 was keenly felt; little help was forthcoming from previous surveys; and everything depended on the way in which photography was carried out and the photographs used. Consequently the question had to be studied from every point of view. The relations of points shown on vertical or tilted photographs to their positions in plan were worked out. The ability of pilots to fly level and to take approximately vertical views was studied. The relations of prints in a series and the possibilities of recording tilt were worked at. I should like to mention the names of Messrs. T. L. Bennett and W. H. Douglas of the Survey of Egypt, and of Lieut. N. Shiels (Australian R.E.) and Captain

F. S. Richards in connection with these investigations. It should be understood that during 1918, when we were concentrating on the work of producing undistorted pictures of the ground, we fully realized the occurrence and effects of tilt, but aimed at its elimination rather than at its correction.

The Work in Central Palestine

At the beginning of 1918 we were much better off for personnel and equipment. We had Bristol Fighters which could easily attain heights of 10,000 to 20,000 feet, cameras were more up to date, and lenses more suitable. More photographs could be taken and dealt with, and it was possible to arrange for one flight of No. 1 Squadron A. F. C. to specialize on mapping photography. The Central Palestine hill country was more difficult ground to deal with, but it possesses many villages whose positions were accurately shown on the 1 inch to the mile map from the survey of Kitchener and Conder, giving a framework of fixed points on which the photographic material could be fitted.

In the district to the east of Jordan, however, the old difficulties were encountered; the old maps were very incomplete and often inaccurate; the number of fixed points was very small; and, in addition, the country was very mountainous. As the result of photography a tolerably good reconnaissance map was produced, showing the wadis, hills, roads and tracks with a moderate degree of accuracy of position. The results showed, when some tests were made, that considerable progress had been made in the elaboration of a system which would give useful results under very unfavourable conditions. The progress made is indicated by the fact that whereas the area mapped on the Gaza-Beersheba front was 400 square miles, subsequent work up to the time of the armistice brought the area up to about 2000 square miles, of which about 1500 square miles was photographed by a C Flight, No. 1 Sq. A. F. C. The country was completely photographed to a depth of about 25 miles behind the Turkish lines, and, in addition, the roads and railways leading northwards out of this area were dealt with.

Methods Employed

The photographic work of the Palestine Brigade R. A. F. was divided into two distinct portions: (a) Topographical work on a small scale under the best possible conditions for general mapping; (b) Intelligence work on trench systems, enemy battery areas, etc., which could, if desired, be incorporated in the maps produced as the results of the former work. The machines carrying out this work were usually at low or moderate altitudes, often under heavy anti-aircraft fire, and were given a good deal of latitude as regards overlapping and straight flying. The topographical photography was kept well ahead, and the country was usually photographed before trench systems and A.A. defences had been established; we shall henceforward deal exclusively with this division of the work.

The great majority of the plates were exposed in a camera of the L-type fixed in a machine with its optical axis vertical and the plate horizontal. Before dealing with

an area, a consultation was held between the officers of the Survey Company and the Royal Air Force at which the general scheme of work was determined. The area was then roughly marked out in a series of strips showing the ground which should be covered by each machine. The arrangement of these strips usually depended on the contours of the country, but the positions of fixed points, easily observable landmarks, and previous work were also taken into account. Most of the strips would be parallel, but some of them would be arranged to intersect the others for the purpose of tying down any series which failed to overlap laterally, and for assisting in determinations of the scale (see figure 1). Diagrams or maps were then prepared for the use of the pilots, showing them the course to be followed, and often amplified by the addition of previous oblique views (panoramic views taken with the optical axis of the camera tilted at an angle of 70° to 80° to the vertical, or with an equivalent prism attachment) or other photographs. In making the final arrangements it was often necessary to take into account the direction of the wind at the required altitude. The camera was mounted in a specially constructed semi-rigid pivoted fitting, which could be adjusted in a fore-and-aft direction so as to bring the plate into a horizontal position which was indicated by a spirit level. This arrangement proved a satisfactory solution for the difficulty of ascertaining the flying position of the fuselage in order to level the camera, because the variation of the incidence of the tail plane in machines like the Bristol Fighter introduces a considerable variation in air speed during flight and consequently in the fore-and-aft level of the fuselage. The pilot was now free to adjust his flying speed as desired, and had only to keep his wings level and his height constant. Considerable trouble was experienced in obtaining comparatively undistorted photographs before the introduction of this fitting, and though it was roughly made it gave valuable results.

In the air the pilot had to concentrate on finding his course and on keeping his machine level, while the observer manipulated the camera. The fitting was first levelled, and then exposures were made at the required intervals either by reference to a sight or by time, or usually by a combination of both methods. After eighteen exposures the plate boxes had to be expeditiously changed so as not to break the sequence of the overlap, and the work was continued until a series had been secured covering the required area of from 5 to 10 miles—or in some cases as much as 35 miles. The pilot would then turn and a second strip would be photographed, and so on until the task was completed and from seventy-two to one hundred and eight plates had been exposed. Often two and sometimes as many as five machines would work together under an escort, so that a very large area was covered in a single morning (see figure 2). Most of the work was done from heights of 10,000 to 15,000 feet, but in hilly country with longer-focus lenses greater heights were often employed. It was not found very practicable to use prints which had a much smaller scale than 1:20,000, and with 6-inch lens this limited the height to 10,000 feet.

On returning to the aerodrome the plates were quickly developed and unglazed contact prints were made, together with a set of enlargements. These were handed over to the Field Survey Company. It may be useful to point out here that if prints are glazed their utility for map-making is entirely destroyed. The resulting image is always

larger than the original negative image owing to the expansion of the paper, and this expansion is greater in one direction than in another. The enlargements are often very useful for reference during compilation and after the contacts have been stuck down and inked up.

We now pass on to the work of the Survey officer who is to compile the Map. After a preliminary examination and identification of the areas which have actually been covered, he sorts out the prints into sets or strips each comprising from ten to twenty prints. Each set would usually contain at least two fixed points, preferably near either end, from which the scale of the whole could be determined. Each print in the set should overlap its neighbours by from 30 to 40 per cent, and the same points on adjacent photographs should overlap accurately. If the overlaps were bad and indicated distortion, the series was usually rejected and a new set had to be taken on another day.

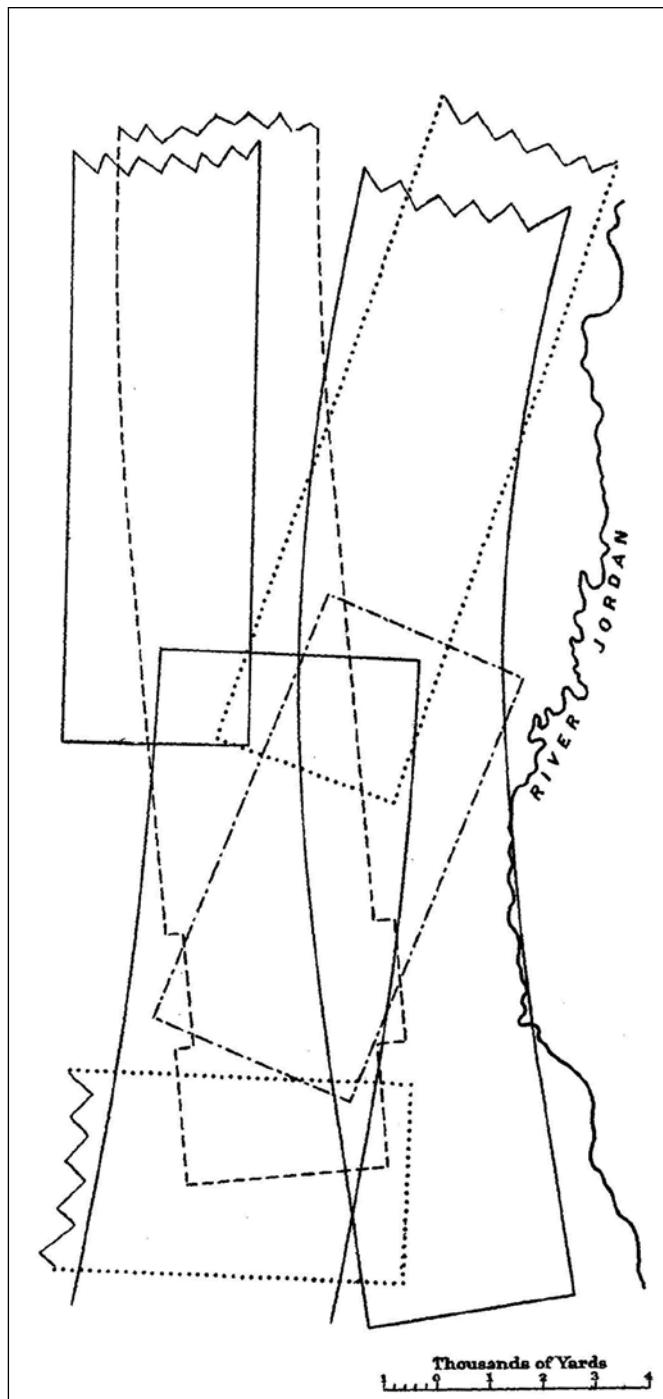


Figure 1. Results of attempt to cover ground with parallel strips of photographs.

The photographs were then pinned down on a large piece of cardboard in their correct relative positions, so that points on one print fitted with those on the next. Any trimming required was done, and eventually the series was gummed on to the card, care being taken that in adjusting the position of the print, points were used which appeared to be on the same altitude and not too near the edges of the picture. The group of prints thus obtained was used as a unit in the map compilation.

All possible points which could be identified on the old map and seemed reliable, or which had been fixed by intersection, were then noted, and by using combinations of these the scale of the group was determined. Several values would usually be obtained for the scale, and if they agreed fairly well a weighted mean value was taken. If the ground depicted changed considerably in altitude throughout the series, special treatment was needed.

The group was then inked up, everything which was to appear on the final map being overlined with transparent coloured ink of an appropriate colour, after which the inked detail was pantographed down to the map scale on a piece of tracing linen. Eidographs by Elliot were chiefly used in this work, and were found to be more convenient than the system of reduction by photography which was used in Mesopotamia. A series of points, such as bushes, rocks, or road junctions, which could be clearly picked out on other series, was also marked, and was later used in fitting together all the material available. In this way all the photographic material was eventually reduced to series of strips drawn on tracing linen to approximately the same scale, and showing everything which was to be included in the final map.

In compiling the map from this material a large sheet of tracing linen was prepared and ruled up with the usual 1000-yard squares. All points which could be fixed by reference to previous surveys or from work done within our lines, were then inserted, and the edges of adjacent completed sheets were also traced on. This served as the framework upon which the rest of the detail was built up.

The next step was to plot a number of secondary points on the sheet by reference to the primary points and the photographic detail, so as to have fixed points every 3000 yards. A pantographed strip was placed in position by reference to the primary points, and the location of some small prominent object seen in the photographs was ascertained. This object would be shown in several strips or groups, and from each of them an independent value for its position would be obtained. A weighted mean position would be taken, and repeating the process for other objects, the sheet was covered with points whose mean positions had been ascertained. The strips of detail were then placed below the sheet, adjusted with reference to the primary and secondary fixed points, and the detail traced in from them. In this way every group was slightly adjusted and errors in scale or azimuth, which may have arisen in the photographs, were distributed, so that no single photograph or group had to be distorted violently, as sometimes happens owing to an accumulation of errors when constructing mosaics. When two values of secondary fitting points were rather far apart, as happens in pictures of steep hilly country taken along the contours, a special method of adding the detail square by square in its approximately correct position was adopted.

Form lines were added to all the later maps, and these were based on the stereoscopic examination of adjacent prints. When the adjacent photographs in a series overlap by 50 per cent., the whole of the area covered can be viewed stereoscopically. If A and B are two consecutive prints, the ground seen on the right-hand side of A is shown on the lefthand side of B, and the stereoscopic base is the distance between the centres of A and B. When the prints are placed side by side and viewed through a stereoscope so that the left eye looks at A and the right eye at B, the relief of the common area is clearly seen after a little adjustment.

The amount of relief seen depends on the height of the camera from the ground and on the length of the stereoscopic base. By inspection in this way the shapes of the hills and valleys can be determined, and indicated by form lines inked in on the prints. These lines can be reduced by the pantograph and shown in the final map. This method gives some idea of the relative heights, and further valuable information can be obtained from oblique views also taken in stereoscopic pairs. These enable the worker to determine which points in a ridge are the highest and lowest. More exact determinations of relief or the estimations of actual contours were not attempted, though methods for doing this were studied.

In concluding this brief sketch of the methods employed in Palestine some remarks may be added as to the degree of accuracy obtained. Capt. F. S. Richards, of the 7th Field Survey Company and the Survey of Egypt, has gone into this question and states: (1) Where the ground was flat and triangulated points close together great accuracy was obtained. Every point was within 40 metres of its correct position and the detail of wadis, roads, fields, etc., was more accurate than ground plane-table survey work done under military conditions. No slopes however can be shown. (2) Where triangulated points are fairly close (an average of four in a square of 6000

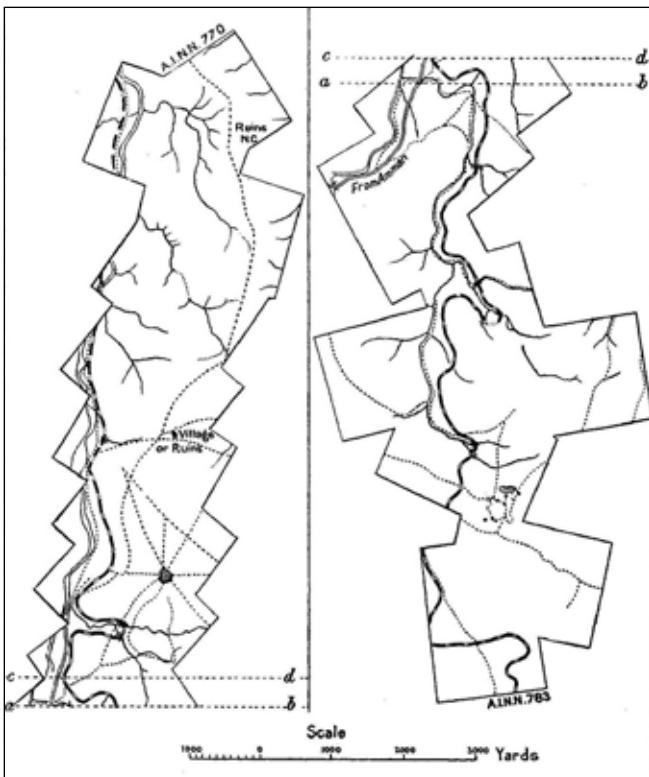


Figure 2. Example of reconnaissance map worked up from a strip of overlapping photographs.

yards sides) and the ground hilly, as in Central Palestine, the maximum error of position of any point is about 200 metres. The shapes of the hills and wadis would again be better than in an ordinary military plane-table survey.^(*) (3) Some sheets were constructed on a very much smaller number of fixed points; in one case only six occurred in a sheet covering 20,000 yards by 28,000 yards, and here again the country was mountainous. In these a maximum error of about 400 metres is to be feared in parts; the general shape of the detail is again good, though its position may be inaccurate.

B. The method which has been described seems to be applicable to the work of geographical reconnaissance in other areas. It possesses the advantages of requiring a comparatively small amount of basal survey work on the ground; it is rapid, enabling large areas to be covered to a considerable distance from the landing grounds; and it does not entail an unduly great labour in the work of compilation. With a moderate number of fixed points and in suitable country, it gives results which are as accurate as are usually obtained in maps on a scale of about 1 inch to the mile, and makes it possible to show the exact shape of the detail without trouble.

We may, however, examine further some of the general ideas underlying this system and notice the types of country in which it is suitable, dealing briefly with the lines along which improvements may be made in the future.

Limits of the Utility of Vertical Photographs

When a photograph of perfectly level ground is taken on an accurately levelled plate with a modern camera whose optical axis is vertical, the resulting plate depicts the ground accurately in plan. Distortion due to the aberration of the lens is quite negligible with a good modern anastigmat such as is usually employed in an aeroplane camera. The error due to the movement of the aeroplane during the travel of the focal-plane blind is negligible at moderate heights and in the case of photographs of a scale of about 1:20,000 but the replacement of the focal plane shutter by a between-lens shutter might be thought of.

In practice, however, the ground may not be flat or the plate horizontal; but in our system the plate is regarded as being so nearly horizontal that the difference from the true representation is small, and does not produce appreciable errors in maps on a scale of 1:40,000. We also assume that it is possible for a pilot to take a series of vertical photographs while keeping his height virtually constant. The grounds for these assumptions must be examined more closely owing to the divergent views which are held on the subject.

It is stated by workers on other fronts that experience shows that aeroplane photographs are always more or less distorted owing to the plate not being horizontal

^(*) That is in a country to which access is difficult, and in which a considerable rate of progress is required by the circumstances.

at the moment of exposure, and if this be the case it is due to one or more of the following causes: (1) The way in which the machine is rigged or flown; (2) The atmospheric conditions; (3) The mounting of the camera in the machine. Suitable photographs cannot be obtained unless attention is paid to all these points.

Pilots usually need training and practice in flying level. On the French front straight flying and consequently level flying was very unwise and unsafe, on account of the enemy anti-aircraft defences, but in the East after training and practice good work was done without special instruments. Experiments made in England during the last two years in connection with aerial navigation similarly indicate that considerable accuracy of position can be maintained. This is increased by the use of special instruments for detecting turning movements and change of altitude.

Atmospheric conditions are often responsible for irregularities in the position of the optical axis of the camera. At low elevations, differences in the density of the air or other causes, give rise to the phenomena known as "bumps," and cause either the sudden fall of the whole machine or the tipping up of one plane. These effects, however, greatly decrease with an increase in height, and at altitudes of about 10,000 feet they disappear, and a perfectly steady wind is experienced, except in certain rare cases. This is an important reason for carrying out survey photography from a considerable height and for using long-focus lenses when larger-scale photographs are required.

The mounting of the camera in the aeroplane is one of the chief causes of distortion due to tilt, but it is also necessary to ensure that the lens is accurately mounted in the camera itself. It is obviously impossible to obtain correct photographs unless the plate is horizontal when the machine is in its level flying position. During the war little attention was given to this aspect of camera mounting, the greater care being paid to devices for the elimination of vibration effects, and consequently the optical axis of the camera was often three or four degrees from the vertical even when the machine was flying straight. Except in Palestine, it was seldom recognized that the level of the fuselage varies with the air speed of the machine, but when the incidence of the tail plane can be adjusted, the air speed may alter considerably, and this may result in the plate being tilted from five to ten degrees out of the horizontal. We found that this was a great source of error when using Bristol Fighters, and, as mentioned above, a special swinging fitting was designed to meet the case. With this mounting the camera could be brought into a horizontal position whatever the slope of the fuselage, and the results gave considerable satisfaction even though the adjustment was made by reference to a spirit level.

It had been argued that a spirit level would not give accurate results in the air owing to changes in the acceleration of the machine, and therefore such an arrangement was only used as a last resource. All recent work, however, indicates that the argument against the use of gravity levels in steadily flown machines, is fallacious. A considerable body of evidence has been collected recently on the accuracy of gravity levels in aeroplanes. Many trials have been made in England and America with both pendulum and bubble levels in connection with sextant observations. As the result of a very

long series of observations made with bubble instruments the average deviation from the horizontal of single readings proved to be no more than $\pm 21'$. These experiments seem to show that it should be possible to mount a camera and to fly a machine in such a way that the optical axis of the camera is never more than half a degree from the vertical at the instant of exposure.

The question of recording the tilt of the camera was considered some time ago, but the difficulty of producing a small and sensitive tilt detector proved insuperable at the time. Messrs. Bennett and Douglas of the Egyptian Survey conceived the system of photographing the horizon at the moment of exposure with two small auxiliary lenses; in practice, however, the horizon was found to be too indistinct to be of practical utility. The German tilt recorders of Zeiss were very neat, but were probably not capable of sufficient accuracy.

The question of maintaining the camera in a vertical position by means of a gyroscopic stabilizer was suggested some time ago, and a considerable amount of experimental work was latterly done on this subject. It cannot, however, be said that the results yet achieved have been entirely satisfactory.

The Magnitude of Errors due to Tilt

I have not yet had the opportunity of comparing closely a good set of photographs with a carefully surveyed map of the ground which they represent, and some comparisons that have been already made by others are open to criticism. We may, however, gain some idea of the magnitude and relative importance of distortions due to tilt by the examination of a series of well-overlapped prints.

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It must be noted that none of these results are strictly reliable because the prints used were all enlargements, and may possess an unknown error if the enlarging lantern was refocussed each time a print was made. It is unfortunate that suitable contact prints are not now available for study, but the experience of the survey officers in the field showed that the quantities investigated were negligible in practice, and little attention was given to the question until the freedom of such photographs from distortion was questioned.

The above measurements brought out another important fact, viz. that a much better result is obtained by discarding any points near the corners of the prints. Now when we have ample overlaps we can trim off the edges of the prints before sticking down, and so use only the parts which are fairly near the centre. This is not a wasteful process because the superabundant parts give useful material for our stereoscopic study of the contouring. It has been shown by M. Clerc (*British Journal of Photography*, vol. 66, p. 298; 1919) that in the case of a tilt of half a degree, the useful surface of a 13 X 18 cm. plate is 12 X 17 cms., and on this surface the error of definition is not greater than '02 cm. [0.02cm], which is equivalent to 2 metres on the ground in a photograph taken with a lens of 26 cms. focal length from a height of 26,000 metres.

In following our method there is no need to trouble about distortions which do not produce errors of scale greater than '5 per cent. [0.5 percent], because when fitting together prints by means of points not more than 4 inches apart, a failure to overlap by one-fiftieth of an inch can be neglected, as it is scarcely possible to fit prints to closer than one-hundredth of an inch. If the original prints have a scale of 1:20,000 and are used for a 1:40,000 map, the possible error is less than the thickness of a line.

The question of errors due to tilt has been dealt with at length, because it is of fundamental importance in our system. If practically undistorted prints can be obtained it greatly simplifies the work of mapping from aerial photographs, and makes the use of the strip system possible for reconnaissance work.

The results obtained in Palestine certainly seem to indicate that such photographs can be obtained even with roughly made camera fittings and without the use of turn indicators, but further experiments are desirable to settle the exact limits of what can be done under favourable circumstances.

The Ground Suitable for Aerial Reconnaissance Surveys

If the ground depicted in a photograph is not flat, but rises steeply on one side, its representation on a horizontal plate is not a true plan but becomes incorrect near the edges of the plate, and the greater the angle of view the greater will be the error. Consequently our system of mapping by aerial photography is more suitable for a flat than for a hilly country. If the height of the hills is small compared with the height of the aeroplane, a fairly useful result can be obtained by flying as high as possible and using a long-focus narrow-angle lens.

In Palestine the principal method of dealing with hilly country was to take series along the general line of the contours so that the scale throughout the series should be even, though it was constantly greater on one side of each photograph than on the other. This inequality in the scales of the two sides results in a group of prints taken on a straight course becoming curved when stuck down, and in a shift of the azimuths throughout. It is often however possible to subsequently straighten out a curved group and correct the azimuths. This may be effected by (1) reference to points fixed trigonometrically, (2) comparison with adjoining photographs taken over flat ground, (3) reference to oblique photographs taken by another camera pointing in the direction of the line of flight. A well-known and useful property of oblique views is that straight lines on the ground also appear as straight lines in the photograph, so that by comparison of oblique and vertical views it is possible to plot series of points shown in the latter which lie in a straight line on the ground. A combination of these methods in Palestine enabled much steep hilly country to be dealt with and maps to be produced which gave a good representation of the ground, though not very accurate as regards the geographical position of detail.

It does not seem likely that the present method of photography on horizontal plates will be suitable without profound modifications for the treatment of high mountain areas such as those on the frontiers of India. Here however a system of oblique

photography may be employed, which would be worked on similar lines to some of the methods of photogrammetry used for ground surveys.

The areas in which our methods will be most useful are those where the country is flat, but much enclosed or possessing numerous trees and hedges. In such country ground survey is slow owing to the large number of stations which have to be occupied, but air-survey is rapid and accurate. Similarly in fairly flat but very broken country in semi-arid regions – bad-land topography of the American terminology – the detail is often too complicated for survey on the ground and travelling is slow, while the air photograph shows all the detail, and as much as is required can be placed on the map.

A subject which must be also considered is the provision of landing grounds for the aeroplane. It will not be possible to use the aerial method of survey in many regions covered with tropical rain forest because of the lack of aerodromes or landing grounds, though in some regions, such as the Amazon basin, it would be possible to use sea-planes or flying boats. It must be remembered, however, that a modern machine has a radius of action of at least 100 miles, and with extra tanks and a peace-time load this radius may be further increased. In many of the less densely populated areas of the world it is not difficult to find open spaces which will serve as temporary landing grounds for a few days, and this is all that is likely to be required.

It is of some importance to consider to what extent aeroplane photography could be used over a country like Afghanistan which is difficult of access, comparatively little surveyed already, and mountainous. Here the present methods will enable us to do little more than produce a picture of parts of the country, or a rough sketch-plan showing a great deal of topographical detail, but having little accuracy as regards position except in the neighbourhood of a few points which have been already fixed. But such a topographical picture would have very considerable value and would greatly assist in the work of future exploration and survey. The execution of such a task as this would involve close attention to another factor which we have hitherto passed unnoticed, that is the estimation of the height of the aeroplane above the ground.

Determination of the Height of the Camera

If the plate is horizontal and the height of the aeroplane from the ground is known, it is theoretically possible to carry out a considerable amount of rough mapping without references to fixed points on the ground from which the scale of the photographs can be determined. The accurate measurement of the height of the machine from the ground is, however, a matter of difficulty at the present time. It has not been found possible to rely upon aneroid readings, though if the instruments were carefully calibrated and temperature corrections applied, we should probably obtain a satisfactory value for the altitude of the machine above sea-level; but even then the height of the ground is usually unknown. There are, however, methods which might be used to determine the height of the aeroplane from the ground and which are worthy of future investigation; some of these may be briefly mentioned.

The optical range-finding method may be used, by fitting small cameras near the ends of the wings and making simultaneous exposures by an electrical release. As the wings are not perfectly rigid an optical arrangement would have to be added to show the mutual relations of the cameras at the instant of exposure, but the difficulties of constructing a suitable apparatus do not seem to be insuperable. A separation of about 30 feet between the cameras would probably give good results up to a height of 12,000 feet from the ground.

Another method involves the use of two aeroplanes, each carrying a camera. One of them would fly about 500 feet above the other, and both would photograph the ground below. The upper machine would always include in its views a picture of the lower machine, and by the measurement of this image the difference in height of the two cameras could be ascertained; knowing the difference in height, we have only to compare the relative lengths between two objects shown on the ground in the upper and lower photographs to determine the heights of both cameras above the ground.

A third method which has been suggested is the automatic exposure of the plates carried by one machine at fixed time intervals, and the calculation of the ground speed of the aeroplane. This again gives a rough method for calculating the length of what may be termed the stereoscopic base from which the measurement of distances on successive prints gives the range to the ground.

These methods all depend on the plates being horizontal; but if the required conditions are fulfilled, we can plot the positions on the ground of detail shown on the photographs from the height and optical constants alone. In addition to this, we become independent of the shape of the ground, and can work out heights of hills from stereo-pairs of prints and plot their positions more or less correctly. But we shall no more be able to attain accuracy over a large area than can be done by a plane table topographical survey uncontrolled by a trigonometrical survey.

The Development of Stereoscopic Methods

Reference has been made above to the application of stereoscopic methods for determining contours, and some notes may now be added as to probable development of this line of work. Two methods have been hitherto suggested for the use of pairs of prints showing the same area of ground from different points along the line of flight of the machine, but neither has yet been developed up to the point of ready practical application.

The system of stereo photo-surveying described by the late Colonel F. Vivian Thompson in the *Geographical Journal* for 1908 is applicable with some modifications to air photography. It may be seen by reference to this paper (p. 541) that if certain conditions are fulfilled, similar results may be obtained from horizontal plates in the air to those obtained from vertical plates on the ground.

The conditions to be attained are that our two photographs must be accurately parallel to each other and horizontal, and that the distance between their centres, i.e. the stereoscopic base, must be known. If the scale of the prints or the height of the

aeroplane above any part of the ground is known, the length of the stereoscopic base can be calculated. The details of the Thompson stereo-comparator would have to be altered to allow for variations in the length of the stereoscopic base, but the principle of the instrument could be employed. Without going into the question in great detail, it may be mentioned that preliminary observations seem to indicate that we have here a method of great utility, and by its means very accurate form-lining can be accomplished even if fairly reliable determinations of height and contouring are not possible to the same degree of accuracy as can be achieved on the ground.

A second method has been studied by Squadron-Leader Burchall, O. B. E., of the R. A. F. School of Photography. The underlying principle is the comparison of the apparent height of an object seen in a stereo-pair of prints with the apparent height of a pair of lines engraved on glass, placed in contact with the prints and capable of movement by a fine micrometer screw, the prints and lines being viewed simultaneously through a stereoscope. This method is a modification of a French method devised by Commandant Coradin, and requires a knowledge of the height of the aeroplane and the length of the stereoscopic base.

The impression gained from the work in Palestine, where only the most unrefined form of stereoscopic examination was used, points to the immense value of the utilization of stereoscopy in aerial photoreconnaissance work. We again depend, however, on the production of views which show no appreciable distortion owing to tilt, though very small tilts do not seem to noticeably alter the form of the country.

The Relation of Photographic Work to Ground Survey

In the preceding sections we have dealt with some considerations which might facilitate the production of sketch-maps in a country which was poor in triangulated points, but the indispensability of a good trigonometrical survey even for the production of reconnaissance maps must be again emphasized. Some recent writers seem to be unaware of the fact that while aeroplane photography can be used as a method of topographical survey, it cannot be used as a method of trigonometrical survey. It scarcely seems possible that aerial work will ever be independent of ground work, and the closer the net of fixed points on the ground the more accurate will be the map produced by aerial photography.

The important question is therefore, what must be the size of triangles in the ground framework to allow the photographic method to be usefully employed? The answer will depend upon the nature of the country and the accuracy of position required. In flat country excellent results will be obtained if fixed points occur at intervals of about every mile, and in small-scaled maps the separation of points by 3 or 4 miles should not introduce inaccuracies greater than those which may be caused by the expansion or contraction of paper or tracing paper during the preparation of the sheets. Again, if we merely require a reconnaissance map to show the principal features, such as roads, rivers, villages and woods in their correct relative position, even though their geographical position is incorrect by half a mile or so, the distances between our

fixed points may be extended to from 5 to 8 miles. So much, however, depends on the country that generalizations are difficult. In Palestine we had to work in both flat and hilly country, but in both regions the photographic methods did provide a means of making useful reconnaissance maps in a short time with a comparatively open network of triangulated points.

When reconnaissance surveys on the ground have to cover wide areas, time does not usually allow the surveyor to draw in small local details accurately, but generalization or omission have to be resorted to. In the case of photography, however, it is possible to trace the detail in its correct shape and to add without trouble many small local features, such as small tributary streams, groups of trees, patches of rock, etc., which will make the map very valuable for subsequent use on the ground. A single aeroplane can photograph 30 square miles of country in a day within a radius of about 100 miles of its landing ground, and an air force unit of six machines (one flight) can cover at least 100 square miles a day and probably much more. Development and printing occupy only a short time, and the main labour is relegated to the compiling office.

In Palestine one officer without help could complete a 1:40,000 sheet covering 20,000 yards by 28,000 yards in six weeks, using perhaps 500 to 700 photographs. This method probably compares very favourably with other methods of map production as regards rapidity. When there is an existing trigonometrical survey, such as in India, we shall only need a ground party to traverse the area and collect information as to place-names, wells, etc., possibly fixing a few additional points also. This high rate of progress will probably render the aerial method an economical one, even taking into account the cost of upkeep of aeroplanes, and if Government aeroplanes maintained for other purposes are used for the work, it means cheapness as well as rapidity. If, however, aeroplanes or sea-planes and their equipment have to be transported long distances to the scenes of operation, it is possible that the method will not be economical unless the area is very large and difficult to survey on the ground. As, however, the air-routes become opened up over the world, the aeroplane or sea-plane survey will become much more practicable.

In this paper attention has been confined to the methods which have been already used with considerable success, and to the discussion of matters arising from them. Consequently nothing has been said about oblique photography and the methods of photogrammetry which may be applied to it. In the early days of the Palestine Campaign I devoted some attention to the question of using obliques for mapping, but found that it was likely to be slow and laborious. The taking and use of oblique photographs was subsequently simplified by the introduction of a prism attachment for the ordinary vertical camera; but we confined our use of obliques to the securing of a preliminary general reconnaissance of the ground before commencing vertical work, or additional information as to azimuths and relative heights. The oblique method of work has however some exponents, notably J. W. Bagley in America (*U.S. Geol. Surv. Bull.* 657, 1917). It probably has a future when applied to mountainous regions.

In dealing with reconnaissance work it must be remembered that sea planes may

be of great use to survey ships in coastal work, because in many places the reefs and shallows below the surface of the sea are clearly seen in photographs. In 1917 aeroplane photography was successfully used for charting the harbour of Rahbeg on the Arabian coast.

It would be too great a digression to describe the work of making town maps of the congested cities of the East, or the contemplated river surveys which are so much needed in the case of some Oriental rivers with unstable courses. At present the main field of activity in the East is in the production of reconnaissance maps of the type made in Palestine, which can be quickly and easily constructed, and which will be useful for both civil and military purposes. Those who have travelled in out-of-the-way regions and those who have at any time been engaged in military work, will realize the great utility of maps which are sufficiently complete in local features to enable one to identify one's position by reference to the map detail. Most of the pre-war reconnaissance maps which I have used in the East, and which would be probably regarded as good of their type, involved the need of constantly stopping to take bearings on some distant known points in order to ascertain one's position, and this is a tiresome proceeding.

Some experiences in the field almost persuade one to put forward the thesis that in a reconnaissance map wealth of local detail and accuracy of relative position, by which the traveller knows exactly where he is and what features he is likely to meet, are to be preferred to a map which is poor in local detail even though the latitudes and longitudes are absolutely correct for those points which are shown. There is much to be said for this point of view, though it is perhaps scientifically unsound.

It is the full and detailed picture of the ground which can be so quickly and easily secured by aeroplane photography; and if methods are forthcoming of utilizing this picture to make a good small-scale map by an easy, rapid, and reliable method, then air photography will have an important future. If, however, the methods are slow and cumbrous they will only be useful in special emergencies.

The work already carried out in Palestine does seem to show that air photography possesses great advantages for reconnaissance work. The actual photography and mapping of 2000 square miles of country must be regarded as a real solid achievement rather than as an experiment. The methods may be criticized on theoretical grounds, but the results are the best answer to such criticism. Work on the same general lines has been successfully carried out in Egypt and Mesopotamia, which also shows that a practicable system has been attained from which much may be expected. Aerial photography must not, however, be applied to purposes for which it is unsuited; it can have no bearing on the geodetic side of survey work, and it is more suited for maps on a medium scale than for very large-scale maps or very small-scale maps.

The methods described have been elaborated by the close co-operation of surveyors with members of the Air Force, and it seems probable that further progress will only be made by the collaboration of the producers and users of air photographs. It is this belief which has prompted the author to contribute this paper.