# Recent Experiments in Aerial Surveying by Vertical Photographs.[1]

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I.

IT is proposed to describe in these columns the results of experiments on aerial surveying that have been in progress at the University of Cambridge since 1920. The experiments were made possible by the co-operation of the Royal Air Force and the Department of Scientific and Industrial Research with the chair of aeronautics at Cambridge. They were suggested in the first place by Mr. Hamshaw Thomas of Cambridge as the result of his experiences of air-mapping in Palestine during the War. The authors wish to acknowledge their debt to Mr. Thomas, not only for the original suggestion, but also for valuable advice during the progress of the work.

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To make an accurate survey by air, it is necessary to have information concerning the position and orientation of the camera at the moment of exposure. If the ground concerned is flat and the tilt of the camera is known, the photograph can easily be re-projected to give a true plan. When the ground is hilly, two photos of the same area, taken from known points, and with known tilts, will provide information from which a complete model, or map with contours, can be constructed.

If three points that are accurately known in position occur in a photo, it is possible to find the position and orientation of the camera from internal evidence in the plate itself. This process is called "re-section." It is thus theoretically possible to map an indefinite area of country from a single base of three known points, for these points could be made to occur in the first two photos, which could then be used to determine the positions of other points, from which further photos could be re-sected, and so on. In practice this process would lead to accumulations of error which, with the methods yet available, would soon become prohibitively large. It is for this reason necessary, if the re-section method is to be used at present, to provide a net of ground-surveyed control points such that three will occur in most, if not all, the photographs.

When the aerial map is merely required to record changes, or to fill in detail in a country that has already been closely surveyed, as, for example, in the war mapping of the Western Front, or in the re-mapping of towns in peace, many accurately surveyed points will already exist and the re-section method will be the obvious one to use. When, however, the problem is to map large areas of unsurveyed country, as, for example, the interiors of Australia or Africa, the cost of providing so many ground-surveyed points will generally be prohibitive. This will be especially the case when the country is flat and heavily wooded.

It is, however, precisely in connexion with large areas of this nature that the outlook for aerial surveying, on a large scale, is most hopeful. In such cases it will not, in general, be practicable to spend much money per square mile of survey, so that it becomes necessary to employ methods that neither require a close preliminary ground survey nor involve too much office labour per photo. Both these conditions rule out the re-section method for work of this class.

Now exact determination of the position and orientation of the camera in space, by methods that are independent of the photo itself, is a matter of great difficulty, but it happens that an exact plan of level country can be constructed from overlapping photos, without knowing the exact position of the camera, provided that all the photos are taken from the same height and with the camera axis vertical. The reason for this is that all such photos will show a true plan of the ground to the same scale, and therefore they can be shuffled together, until the detail joins up everywhere and a true plan is formed.

If, therefore, a camera can be kept at a constant height, with its axis vertical, and moved about over the ground, so that the whole country is covered by overlapping photos, it will be possible to construct a continuous plan of the ground from contact prints straight from the original negatives; and it will not be necessary to provide for known points to appear on each photo, or to determine the position of the camera at each exposure. Moreover, the heavy office work involved in re-secting and re-projecting each photo will be avoided entirely.

Such a process is strictly accurate only when applied to absolutely flat country, but when working from 10,000 feet, as we do, undulating country up to about 500 feet local differences of level can be classed as sufficiently flat from this point of view. It must also be remembered that flat country is often the most difficult to survey from the ground, and is therefore the country in which an alternative method is most required.

We are thus led to the conclusion that the economical mapping of moderately flat country, by means of vertical photographs, depends upon the accuracy with which the camera can be maintained at a constant height, with its axis vertical, and upon the ability of the pilot to fly so as to cover all the ground with photographs that will neither overlap too much nor leave gaps. The experiments at Cambridge have been concerned mainly with the accuracy obtainable in these operations, given suitable apparatus and sufficient training in air routine.

### FINDING THE VERTICAL.

The problem of keeping a constant height is quite straightforward and easy to understand; the only difficulty is to do it. The problem of keeping the camera axis vertical is complicated by the fact that all forms of apparatus that are designed to indicate the vertical are disturbed by horizontal accelerations of the aeroplane, which often persist in one direction for so long as twenty seconds at a time. It is possible to devise gyroscopical instruments that will seek the vertical so slowly as to average out these disturbances, but much experience has been gained with instruments of this type during the War, and this experience was not encouraging, mainly owing to the liability to failure of the delicate apparatus required.

In aerial surveying it is, however, necessary to fly

[1] Substance of two lectures delivered at the Royal Institution on February 15 and 22.

very straight and steadily in order to cover the ground correctly, and, when one is flying straight and steadily, simple vertical indicators such as the spirit level indicate truly.

Now it had been found, in connexion with bombing experiments during the War, that it is comparatively easy to fly very straight and steadily when no other condition is imposed, but that it is much more difficult to do so when trying to pass over a pre-arranged point. The reason for this is that the pilot normally estimates the horizontal and vertical by reference to the horizon, and, when forced to look at the ground beneath him, is quite unable to distinguish the true vertical from the apparent vertical as distorted by acceleration.[2] It is obviously necessary to look at a point in order to get over it, so that the reason for the distinction between merely flying straight and flying straight over an object is at once apparent. To overcome this difficulty it is necessary to devise methods of carrying out the survey with the minimum attention to the ground beneath.

We decided to divide our experiments into two groups as follows:

1. To study the accuracy with which it is possible to keep the camera at a constant height with its axis vertical, when the difficulty of finding a predetermined track is reduced to a minimum.

2. To find out how to fly over a predetermined straight track without losing accuracy from that determined above.

In connexion with the first group of experiments, we were fortunate in having near Cambridge a stretch of very flat country covered with numerous well-mapped and easily identified points and traversed by two large straight canals, more than twenty miles long, called the Bedford Levels.

It is easy to fly down a long straight landmark of this nature with very little attention to the ground immediately beneath. We therefore flew along these canals at about 10,000 feet, keeping as straight and level as possible, and taking a series of photographs at regular intervals. We then developed these photos and, from them and a 6-inch Ordnance Map, calculated the position and orientation of the camera at the moment of exposure by the method of re-section.

The re-section was very laborious, but eventually, after about two years' work, we obtained results for 170 exposures, and these showed a probable error of tilt of about 1° from the vertical and a probable variation of height from the mean of a flight of 40 feet. The distribution of errors in both tilt and height was quite normal.

From this data it is clear that the tilt of the camera axis from the vertical seldom exceeded 2° and that the height of the camera seldom varied more than 100 feet from the mean of each flight. Simple calculations, supported by previous experience in Palestine, lead to the conclusion that such errors should not introduce serious errors into maps made on the assumption that the axis is vertical and the height constant. This excludes, of course, errors that are cumulative over large distances.

[2] It is easily shown that a pilot, looking down at a point beneath him and trying to fly so as to pass over it, will tend to fly along one of a series of curves of which the equation is $p\rho$=const., where $p$ is the perpendicular from the origin on the tangent from the point where the radius of curvature is $\rho$. These curves in general never pass over the required point (*i.e.* the origin).

### COVERING THE GROUND WITHOUT GAPS.

The second problem was to cover the required country to be surveyed without leaving gaps and without losing accuracy. It is on this problem that most attempts at commercial surveying have broken down, the primary cause of failure being the inability of the pilot to distinguish between the true and apparent vertical. So long as the pilot is allowed to look constantly down at the ground, in an endeavour to cover it accurately, tilts up to six or more degrees are liable to occur, and the tracks that are made under these conditions are often so curved as to cause large gaps between the strips of photos.

By experiment we have found that the best way to solve the difficulty lies in allowing the pilot to locate his position by reference to the ground beneath, at the start of each flight only, and insisting that he must fly henceforward without further reference to the ground.

To do this in such a way that successive flights on the out and return journeys will cover the ground in parallel strips, it is necessary, first, to find and allow for the wind at the height in question. This we do by a method that was developed by the Air Ministry for purposes of aerial navigation, and we have brought the routine to such a pitch that within ten minutes after reaching the survey height, 10,000 feet, we can find the wind and make all necessary calculations for compass courses, etc. It requires considerable training and experience before this can be done.

However good the methods employed, the strips on successive journeys will not be exactly parallel, and, since they are located only at one end, their length will obviously be limited if gaps are to be avoided. We find that this limit comes out at between 10 and 15 miles. The starting points for the strips are either marked on existing maps or on preliminary strips of photographs, taken along the edges of the mosaic at right angles to the mosaic strips; these preliminary strips are called "indication strips."

The pilot, therefore, begins by getting over a point, as accurately as he can, and then taking up a pre-calculated compass bearing as quickly as possible. A difficulty may here be experienced owing to the well-known fact that compasses on aeroplanes are affected by a change of course and do not settle down on a true bearing until the aeroplane has been flying straight and steadily for some time. If the pilot has managed to get over the starting point while flying on the correct bearing, this difficulty will not arise, but when working from tractor aeroplanes, as we are forced to do, one cannot always manage this, because the lower plane obstructs the view of the point during the approach, unless the approach is made in a curve.

To overcome this difficulty we use an apparatus designed by the Royal Aircraft Establishment. This consists of a free gyro that can maintain its orientation in space for some ten minutes, without reference to the movements of the aeroplane. We release this gyro while flying on the required course, just before reaching the starting point, and use it to return to the correct course immediately after passing the point. We consider that an apparatus of this nature will always be a great help in aerial surveying, especially when working from tractors, but we think that a survey could be successfully carried out without it when working from pushers. When flying without this apparatus, either more skill is required, or the beginnings of each strip will be rather less accurate than they might be.

The photographic strips themselves can be kept straight by flying on a distant point near the horizon, but this operation can be much assisted by another gyro instrument that controls the rudder through a relay and thus keeps the aeroplane on a straight course automatically. This apparatus relieves the pilot of the most fatiguing part of his work and, by allowing him to concentrate more on such things as maintaining constant height and speed, improves the general quality of his work. We have carried out surveys both with and without this instrument, and, while we have proved that accurate work can be done without it, we should always recommend its use in any large surveying scheme.

### AREA COVERED IN A FLIGHT.

We have found from experience that 100 sq. miles is about the area that can conveniently be covered in one flight. This requires about 80 minutes flying on the actual mapping and about three hours from ground to ground. This amount of work is about what a crew can perform regularly, day by day; hence it follows that aerial surveying by these methods can be carried out at the rate of about 100 sq. miles per day. If the separate strips are made ten miles long, the average day's work will, therefore, cover a square of ten miles to the side.

We have found that an area of 100 sq. miles, involving about 130 photos, forms a convenient unit for compilation, for, although we have compiled a very successful map of 225 sq. miles in one unit, we consider this to be too large for economical work. The method, therefore, that we favour for mapping large areas, is to compile the prints of each day's work into separate mosaics and, after reproducing these to any required scale in a large camera, or photostat, to fit these larger units together in the same way as the individual prints were fitted.

(*To be continued.*)

## Science and Radio-Communication.[1]

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PROBLEMS in which there is a close connexion between theory and practice can be found in every branch of engineering, perhaps with more striking effect in electrical and metallurgical science, in the laws of stress and strain in structural materials, and in the fatigue of parts subject to vibration, rather than in the questions which pertain more closely to the domain of civil engineering. Let me deal first, briefly and incompletely it must be, I fear, with that branch of electrical engineering—radio, or wireless telegraphy—which at present exercises such a fascination over the popular mind, which is already and will be to a greater extent in the future a link to bind together all nations of the earth. Sir William Anderson, in the first James Forrest lecture delivered thirty years ago, refers to Preece's early experiments between Lavernock and Flatholme, a distance of eight miles, as a startling consequence of electro-magnetic theory. Now the earth is girdled with a wireless chain depending from two, or at most three, great stations. I have just received from the International Union for Scientific Radio Telegraphy details of a scheme for the determination of longitude in which the principal co-operating stations will be Bordeaux, Annapolis, and Pearl Harbour.

In the year 1865 Clerk Maxwell read before the Royal Society his paper on "The Equations of the Electro-Magnetic Field." It was an attempt, which has stood the test of time—the conditions which led Lorentz and, later, Einstein to introduce certain modifications were not dealt with by Maxwell—to apply mathematical reasoning to those principles, enunciated by Faraday, on which the construction of generators and motors, transformers, and practically all electrical machinery is based. This reasoning led him to the result that the effect of changes in an electric current in a conducting wire would be propagated through space with a speed depending on the two constants[2] which define the electric and magnetic conditions of the medium surrounding the wire. The values of these constants for air can be found from electrical considerations, and hence the velocity with which electro-magnetic disturbances are propagated can be calculated. To quote his words:

> "We now proceed to investigate whether these properties of that which constitutes the electro-magnetic field, deduced from electro-magnetic phenomena alone, are sufficient to explain the propagation of light through the same substance," and his conclusion is: "The agreement of the results seems to show that light and magnetism are affections of the same substance and that light is an electro-magnetic disturbance propagated through the field according to electro-magnetic laws."

Maxwell found that when the calculations were made the resulting value for the velocity was approximately equal to the velocity of light. The work was extended in his "Treatise on Electricity and Magnetism," published in 1873. The values of the velocity of light and the velocity of propagation of electro-magnetic waves were not known then with present-day accuracy, and he concludes that they are quantities of the same order of magnitude. A glance at present-day[3] figures shows that they are identical, and the electro-magnetic theory of light is universally accepted. Nor was the result true only for propagation through air or interstellar space; such observations as were then available showed that, in all probability, it held for all transparent media, though there were discrepancies, known now to

[1] From the James Forrest lecture on "The Interdependence of Abstract Science and Engineering," delivered before the Institution of Civil Engineers on May 4.

[2] The velocity is given by $1/\sqrt{\mu k}$, where $k$ is the inductive capacity and $\mu$ the magnetic permeability of the surrounding medium.

[3] Messrs. Rosa and Dorsey of the Bureau of Standards, discussing the various determinations of the electro-magnetic velocity, express the view that the figure $2{\cdot}9980 \times 10^{10}$ cm./sec. is accurate to 1 part in 10,000, while the best result for the velocity of light is, to the same accuracy of measurement, $2{\cdot}9986 \times 10^{10}$ cm./sec. See "Dictionary of Applied Physics," vol. ii.