result either by means of computation or by successive approximation. The only instrument built on fundamentally correct design is the Fourcade Stereogoniometer (Barr and Stroud).

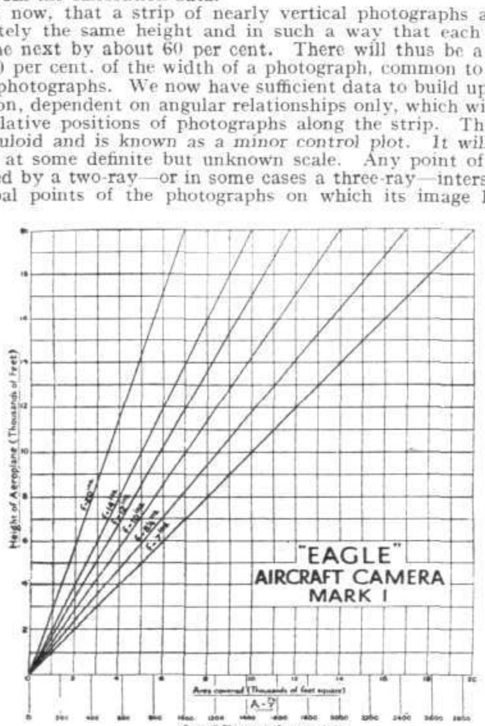
Simplifications in Case of Vertical Photography

Consider the case of a pair of overlapping photographs taken as far as possible at the same height and with the axis of the camera vertical. When set in a plotting machine, therefore, the two photographs will lie in very nearly the same plane. Consider, therefore, a simplified form of stereoscope in which the photograph holders are not goniometers, but flat turntables. The photographs are placed on the turntables, with their principal points at the centres of rotation, and are oriented in their own plane. When viewed stereoscopically they will present a relief model, though slightly distorted, since angular relationships are no longer true. Provided, however, that the tilts on the photographs are small, and that we possess a series of spot heights obtained by a ground survey covering the common overlap, we may draw contours on this relief model which are sufficiently accurate for topographic purposes.

The instrument necessary is small, of simple construction, and correspondingly cheap. The floating mark consists in this case of a grid which can be adjusted so as to appear to float horizontally in space at any desired height. The contours are drawn on the photographs themselves, and are then similar to nature in detail. We require now some method of plotting detail.

A vertical photograph of flat country would (within the limitations of lens distortion) be a true plan of the ground. If a photograph is tilted, the result is no longer a true plan, since the scale will be different in different parts of the picture, being, in fact, smaller on that side of the negative tilted towards the ground, and *vice versa*. In practice, however, the ground is seldom absolutely flat, and there are further distortions due to variations in ground height. On a vertical photograph, for instance, every contour is photographed at a different scale, the tops of hills being at a larger scale than the bottoms of valleys. It is found, however, that provided tilts can be kept to within two degrees of the vertical, and ground heights do not vary by more than 10 per cent. of the altitude of the aircraft, we may take the principal point itself as being angle true. This, being a function of the camera only, is available from the calibration data.

Suppose, now, that a strip of nearly vertical photographs are taken at approximately the same height and in such a way that each photograph overlaps the next by about 60 per cent. There will thus be a small area, in width 20 per cent. of the width of a photograph, common to every three successive photographs. We now have sufficient data to build up a graphical triangulation, dependent on angular relationships only, which will determine the true relative positions of photographs along the strip. This is carried out on celluloid and is known as a *minor control plot*. It will be true to shape, and at some definite but unknown scale. Any point of detail may now be fixed by a two-ray—or in some cases a three-ray—intersection from the principal points of the photographs on which its image lies. If the



AREA COVERED *and* SCALE *of* PHOTOGRAPH
with lenses of different foci
on a
7" x 7" PICTURE

positions of any two such points have been determined by ground survey, then the scale and orientation of the minor control plot are fixed.

When it is required to survey a large area, strips are flown parallel to each other and with a lateral overlap of about 25 per cent. between adjacent strips. In this case a minor control plot is constructed for each strip, and these will all be at different scales. The next stage, therefore, is to bring them all to some common scale. A grid, known as a master grid, is constructed to represent 1,000-m. squares (say) on some definite scale approximating to the scale of the photographs. On this are plotted all the points whose positions are available from ground survey and which can be identified on the photographs and intersected on the minor control plots. A control equivalent to a second-order triangulation will be sufficient. All strips are then tied in to this framework of ground control, suitable points being chosen in the common lateral overlaps to ensure exact agreement between adjacent strips. The result is a series o principal point traverses plotted to the same scale and in their correct relative positions on the master grid.

Finally, a sheet of celluloid of convenient size is placed over the master grid and the principal point traverses are traced off. On this sheet the detail is plotted from the photographs by placing them under the corresponding principal points and in the correct orientation, and carrying out a series of intersections and interpolations. All detail drawn in this way will be plottably accurate. Contours are transferred from the photographs similarly.

All mapping material thus obtained must be fair drawn according to the conventional signs and symbols adopted for the map. Plates are then prepared for as many colours as are required, and the map is reproduced and printed in the ordinary way.

The Air Photographic Problem

With a view to carrying out the above technique we may state the demands of the surveyor as follows:—

(1) Photographs should be taken in strips, flying a straight course at a constant height, usually 15,000 ft. above ground level.

(2) The fore and aft overlap between photographs along a strip should be 60 per cent.

(3) The lateral overlap between adjacent strips should be 25 per cent.

(4) The tilt of the camera at exposure should be kept as small as possible, and should not exceed 2 deg.

The characteristics desirable in an aircraft for survey photographic work may be summarised as follows:—

(1) Endurance.—An endurance of 6-8 hr. is desirable.

(2) Comfort.—To ensure accuracy in navigation and camera operation under extreme cold, comfort is essential.

(3) Stability.—The greater the aerodynamic stability, the better the quality of flying.

(4) View.—The pilot must have a good view ahead and to both sides, and the instruments used for maintaining the correct course, height and level should all be grouped near to his normal line of sight.

(5) Speed and climbing.—Speed is useful in climbing to the required height and when photographing some way from the aerodrome. For actual photography, however, a steady cruising speed of about 100 m.p.h. is probably the most suitable. When photographing hilly country, a machine with high performance is required to reach the necessary height with full photographic load.

(6) Multi-engine.—For large surveys, and particularly in country unfriendly to a forced landing, a triple-engined machine, capable of maintaining level flight on any two engines, has the advantage of greater security.

To photograph a strip it is usually necessary either to fly between two observed points, maintaining a straight and level course, or to fly over a given point, maintaining thereafter a given compass course. Both of these methods entail the determination, either directly or indirectly, of the speed and direction of the wind. This, added vectorially to the air speed, determines the ground speed, the difference in direction between the two latter being the angle of drift. The duties of the photographer are :—

(1) To determine the wind speed and direction and direct the pilot on to the correct course.

(2) To turn the camera through the angle of drift so that the photographs are not "crabbed."

(3) To trim the camera level when steady flight at the required height has been achieved.

(4) To set the time interval between exposures necessary to produce the required fore and aft overlap.

The time taken in carrying out the above operations will depend on the methods and instruments used and on the skill of the photographer and pilot, but the interval between taking off and starting photography, even close to the aerodrome, will seldom be less than 50 minutes. Sound meteorological information is therefore essential, particularly in cases where changes of weather are rapid.

As an aid to straight and level flying, gyroscopic control has been introduced. The results are remarkable. Tilts are reduced to less than half a degree, and strips are practically straight. The effect of this is greatly to increase the validity of the assumptions made in the simplified method of plotting, and to extend its application to conditions of very scanty ground control where a solution would otherwise hardly be possible. The gyroscopic control of aircraft for air survey purposes is therefore of the highest importance, and no survey of any large area should in future be undertaken without it.

Air Survey Procedure

We are now in a position to outline a suitable procedure for embodying the above technique, and to estimate some of the quantities involved. The process may be sharply subdivided into three sections:—(1) Air photography; (2) Ground survey; (3) Drawing office work.

It must be emphasised, however, that efficiency in any one section can only be achieved along with an accurate and sympathetic understanding of the work of the others.

(1) *Air Photography*

The procedure has been outlined above. The camera used in the R.A.F. at the moment is the Automatic Film Camera F. 8, fitted with an $8\frac{1}{4}$ in. lens and taking a photograph 7 in. square. When flying at 15,000 ft. the area covered by a single photograph is, therefore, about $5\frac{3}{4}$ square miles. Maintaining the normal overlaps, an estimate of about two square miles per photograph will give the number of photographs required to cover any given area. With suitable weather, the rate of photography when once started may be taken as about 200 square miles per hour.

To navigate the flights in the most efficient manner, a network of strips will first be flown to cover the area with a skeleton framework. This is plotted first of all, and on it are laid down the centre lines of the various strip flights required. The photographs crossed by these flight lines are used later by the pilot to check his course for the filling-in strips.

(2) *Ground Survey*

The ground survey party should, where possible, carry out a second order triangulation, or equivalent traverse work, and fix a number of spot-heights. They are recorded and marked on the photographs themselves, which are mounted into albums for use in the field.