## CHAPTER 4

# *Flying for Cover*

In Britain, and especially in the Royal Air Force, it is usual to speak of a single flight of an aircraft from take off to touch down as a *sortie.* It has thus become usual to speak also of the set of photographs taken during one flight for mapping purposes as a *sortie.* A photographic sortie will usually be flown for the specific purpose of taking photographs sufficient to enable the mapping of a definite area of land to be carried out by photogrammetrical methods. However, one sortie might cover two or more entirely separate areas. When an area of ground has been covered by a satisfactory sortie, we say that *air cover* for that area is available.

The main objects of flying for air cover will be to obtain, in the quickest and cheapest manner, a set of photographs which will enable the surveyor to carry out the necessary plotting of the required map.

To secure satisfactory air cover the following points must be considered—

1. Proper equipment must be used. This aspect will be further discussed in Chapter 9.
2. Weather conditions, including height and intensity of the sun, must be favourable.
3. The flying height is so chosen that, with the given lens, contact prints of a suitable mean photo scale are produced.
4. The whole area must be completely and systematically covered so that adequate stereoscopic vision of the land is possible.
5. The optical axis (principal axis) is sufficiently nearly vertical at the time of exposure.

Taking each of these points in turn—

1. EQUIPMENT. The aircraft itself must be specially adapted to carry the air camera and viewfinder. Until recent years a slow-flying but stable aeroplane was the rule; but nowadays moderately fast speeds can be tolerated. The aeroplane must be capable of flying on an even keel at the height required, and at the same time carrying the camera and the operator, who will often also be the navigator. Many different types of aircraft have been successfully used for

this purpose, and it is unusual for a specially designed plane to be advocated. The direction along the keel, from nose to tail, is known as *fore and aft*, and the direction from wing tip to wing tip as *lateral*.

The camera is a precision instrument designed for the specific purpose of air photography and was described in Chapter 1. This instrument is gimbal-mounted in the fuselage or body of the aeroplane, so that it can be turned through any vertical or horizontal angle with respect to the aeroplane's axes.

The camera is mounted in the inner ring of the gimbal (see Fig. 1.17), in such a way that the optical axis is perpendicular to the plane of the ring, and passes through the centre of the ring. The instrument is free to rotate about the optical axis within the ring, and can be set so that the side of the format makes any desired angle with the fore-and-aft direction of the aircraft. This angle is known as the *drift ring setting*.

2. WEATHER CONDITIONS. When an old steam-engine belched out steam and smoke from its funnel, it caused dense, whitish, turbulent clouds; you could see the air currents at work. The similarity between these artificial clouds and the billowing mountains of cumulus cloud is most striking. The obvious turbulence of the cumulus cloud is evidence of strong, often upward, air currents. Such currents may occur elsewhere than within cloud formations. Other disturbing influences are air pockets, in which there is a sudden downward current of air. All these disturbances seriously affect the stability of relatively slow-flying aircraft, and photography should not normally be undertaken when such turbulence is known to occur at flying heights.

Photographs cannot normally be taken through cloud or fog; smoke, dust and haze all affect the photography adversely. However, if the sun is too intense the shadows of the photograph become too dense, and obscure the detail. For this reason a thin film of high cloud known as cirrus will be an asset as it will lessen the sun's intensity without causing any obstruction between the lens and the ground.

Bad weather conditions, including rain, are obviously to be avoided, but heavy rain tends to wash out the suspended dust and smoke from the atmosphere. A bright day following a day of heavy rain will often be best for air photography, especially in or near large cities. Lying snow will obscure ground detail, but may be desirable for special purposes. Intense cold may affect the camera, and although heating can be provided, it is very expensive and is not usual at normal flying altitudes in mid-latitudes.

Shadow tends to obscure detail, so that the sun should be fairly high in the sky to give a reasonably short shadow. However, the shape of a shadow is often the best guide to the identity of a ground object from the air, so that the shadow must not be too short. It is usually considered that the photography should be undertaken when the sun's rays make an angle with the horizontal of between say 30° and 65°.

In many countries there will be very few days during any year on which satisfactory air photography could be undertaken. In the British Isles in particular, there is little likelihood of knowing in advance when these suitable days are to occur. Thus it may be necessary for aircraft, camera and crew to stand by for many days before the desired sortie can be flown successfully. This keeps the cost of flying for cover somewhat disproportionately high.

3. FLYING HEIGHT. When simple plotting methods are to be used, the mean or average scale of the air cover should be approximately the same as the desired scale of the compilation drawing. Thus with a given focal length of camera lens, and a given compilation scale, the necessary height of aircraft above mean ground level can be calculated. Flying height, being the height above sea level, can then be found by adding in the mean height above sea level of the ground. Figure 4.1 is a development of Fig. 2.5 and illustrates that scale of photograph $= f/(H - h)$. Thus, if scale required is 1/10,000, focal length of lens is 150 mm, and $h$ is 100 m above sea level,

then
$$1/10{,}000 = \frac{0{\cdot}150}{H-100}\text{ m}$$

i.e.
$$H-100 = 1{,}500\text{ m}$$
$$H = 1{,}600\text{ m}$$

i.e. flying height must be 1,600 m.

Given the same focal length and the same size of format, the higher the aircraft flies the greater the area of ground covered, and the less the number of photographs required to cover any particular area of land. From this point of view the greater the flying height, the more economical the coverage.

On the other hand, the less the flying height, the greater the scale, the more detail that can be readily discerned and the greater the heighting accuracy. Similarly, a greater flying height increases the thickness of haze and dust that the light rays must penetrate, with consequent loss in quality of the photograph. Furthermore the cost of high flying exceeds the cost of flying at lower altitudes.

Air cover is nowadays often flown at over 10,000 m, but the difficulties involved at such heights are immense. The average human body can cope with altitudes of up to 3,000 m, but even at such heights temperatures may be 18°C less than at sea level, and the pulse rate will have quickened due to the decrease in atmospheric pressure from about 101 kN/m$^2$ at sea level to 70 kN/m$^2$ at 3,000 m. Higher than this, the decrease in the oxygen supply tends to affect the normal functioning of the brain, and at about 4,500 m mental processes tend to slow down. As height is increased so the human body would gradually lapse into a state of coma, which is reached at something over 7,000 m. Thus oxygen should normally be taken at heights exceeding 4,500 m. Over about 10,000 m oxygen will usually be required under pressure, and at somewhere near 12,000 m even oxygen under pressure will be insufficient to prevent a lapse into a state of coma. Pressurized cabins in the aircraft can overcome these difficulties, but this necessitates additional cost. High altitudes call for additional clothing which, in turn, reduces efficiency in operating the instruments. The instruments themselves and the materials used in the photographic processes are also adversely affected by the intense cold, and it may be necessary to supply some heating for the instruments. In addition to pressurizing and heating, the aircraft used for higher altitudes will require much more power, and construction and design costs will be very much heavier.

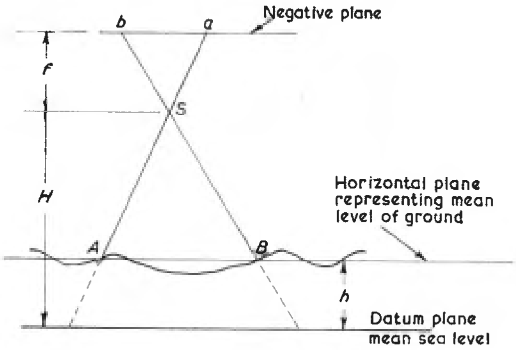


FIG. 4.1. SCALE OF A PRINT
*A* and *B* are two ground points occurring at the mean height of the ground covered by the photograph.

Normal flying heights may be considered as, say, 1,000 to 4,500 m above ground level, so that we may expect flying costs to increase in mountainous areas. We shall see later that in determining the flying height, not only must we consider the scale required, but also the limitations set by the mechanism of the camera, and by the errors due to height distortion. Improved techniques and knowledge are leading to a gradual relaxation of height restrictions in flying for cover.

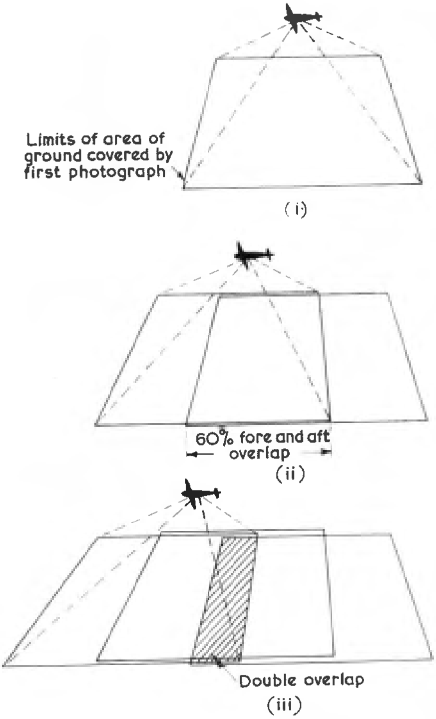


FIG. 4.2. COVERAGE OF PHOTOGRAPHS SHOWING OVERLAPS
(i) FIRST EXPOSURE
(ii) SECOND EXPOSURE
(iii) THIRD EXPOSURE
Perspective views of ground covered by the first three photographs of a strip.

4. COVERAGE. Systematic coverage is obtained by flying the aircraft at a fixed height, and in a series of straight lines. As the aircraft flies along one straight line photographs will be taken at regular intervals. The photographs taken during the time that the aircraft flies along any one of these straight lines are known collectively as a *strip*. Each photograph in a strip should overlap its

predecessor by 60 per cent (see Fig. 4.2). This is known as the fore and aft overlap. It will be seen in Fig. 4.2 (iii) that there is an area of land covered by each of the first three photographs. There will also be such an area common to any three consecutive prints, and it is known as the *double overlap* (or supra lap). On a perfectly flown strip the double overlap will comprise 20 per cent of each of the three photographs of which it forms part.

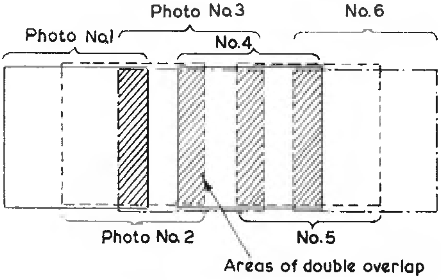


FIG. 4.3. PLAN VIEW OF A STRIP OF AIR PHOTOGRAPHS
Each photograph is set out relative to its correct plan position.

Figure 4.3 shows that 20 per cent near one edge of photo 3 covers ground which also appears on photos 1 and 2. The middle 20 per cent of photo 3 will also appear on photos 2 and 4, and that 20 per cent near the leading edge of photo 3 will also appear on photos 4 and 5. Thus a total of 60 per cent of photo 3 should appear on two other photographs as well.

Having flown one complete strip the aircraft must turn round and fly back along another straight line parallel with the first, again taking photographs at regular intervals so that each new photograph overlaps its predecessor by 60 per cent. The second strip of photographs must also overlap the first strip; this is known as the lateral overlap (see Fig. 4.4). Where the photographs may be wanted for making a mosaic or photo-map, then the lateral overlap must be 30 per cent. For other purposes 20 per cent lateral overlap is usually considered to be sufficient, though some authorities maintain that 25 per cent should be specified.

This means that, as each photograph in the first strip is taken, only 40 per cent of the format area covers new ground, and we say that the net gain is 40 per cent. Similarly each new strip, when a 30 per cent lateral overlap is specified, will gain only 70 per cent of the full width. Thus only (70/100) × (40/100) = 28/100 or 28 per cent of each photograph covers " new " ground. These facts become important when we try to calculate the number of exposures required for complete air cover of a particular area of land.

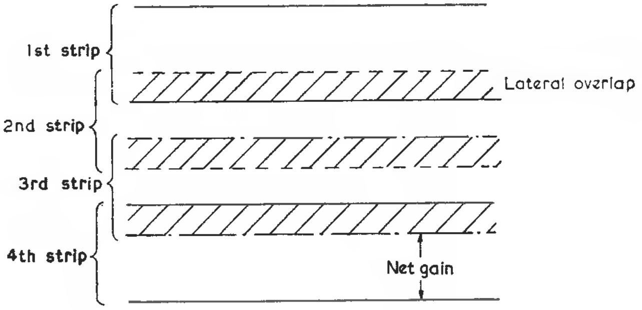


FIG. 4.4. PLAN SHOWING LATERAL OVERLAPS

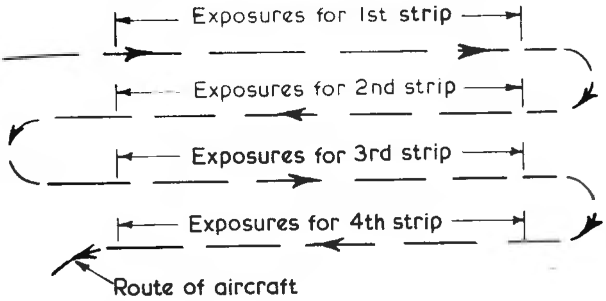


FIG. 4.5. A TYPICAL FLIGHT PLAN
The separation of flight lines to give a 20 per cent lateral overlap is equal to 80/100 × width of format × 1/scale.

The strips can normally be flown in a direction parallel with the longest dimension of the land to be covered (see Fig. 4.5). In temperate latitudes there is some advantage in flying east to west and west to east, because it will then always be possible to set the photographs under the stereoscope so that the shadows fall towards the observer. When this condition is satisfied it is easier to arrange the lighting in the laboratory to give the most satisfactory fusion.

If navigation were by compass, then there would be a definite objection to north–south flight lines, in that the needle would normally be thrown temporarily off balance at the turning points.

Unless radar is being used, navigation in a straight line involves flying along a prearranged course, throughout the length of which known ground objects at perhaps fifteen to twenty mile intervals are discernible from the aircraft. If no map of the area exists, it may be necessary to fly a skeleton cover of the area and prepare a rough photo map merely for purposes of navigation.

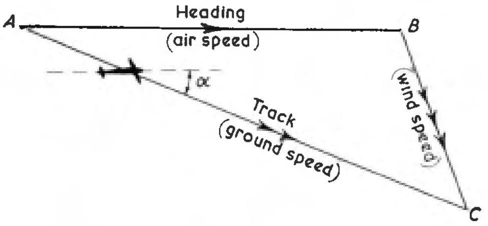


FIG. 4.6. DRIFT OF AIRCRAFT CAUSED BY A CROSS-WIND

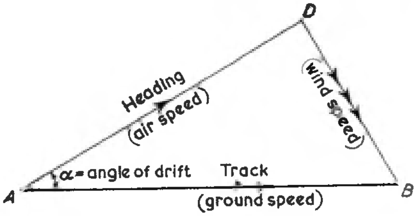


FIG. 4.7. DIAGRAM FOR CALCULATING THE ANGLE OF DRIFT

Suppose that when the aircraft reaches its required flying height there is a cross-wind blowing, such that if the plane heads from *A* to *B* (see Fig. 4.6) it actually travels along the line *AC*. If photographs were taken the result would be a strip of photographs along the line *AC*, which is known as the track of the aircraft. Throughout the flight along *AC* the fore and aft direction of the aircraft (or the heading) is assumed to have been parallel with *AB*. If the distance *AB* in Fig. 4.6 represents, to scale, the air speed in say km per hour, and *BC* represents the velocity and direction of the wind speed in km per hour to the same scale, then *AC* is the resultant and represents the ground speed of the aircraft in km per hour. The air speed is the speed of the aircraft relative to the air, whereas ground speed is its speed relative to the ground. Alternatively, ground speed can be described as the speed with which the plumb point traverses the ground.

Suppose that the strip is required to be flown from *A* in the direction of *B*, i.e. along *AB* in Fig. 4.7. The navigator must calculate $\angle DAB$, so that he can head the aircraft correctly. This angle is the *angle of drift* and is usually denoted by $\alpha$. Let us assume that we are required to find the angle of drift in the following circumstances.

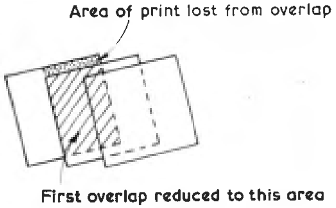


Fig. 4.8. Loss of Overlap due to Crab

Required direction of track is due east; air-speed of aircraft is 300 km/h; the wind has been determined as from the north-west with a velocity of 50 km/h.

The figure required is similar to Fig. 4.7, though there *DB* is of exaggerated length and the angle of drift therefore appears too big. The triangle can be solved by the sine rule.

$$\angle DBA = 45^\circ$$

$$\frac{\sin\alpha}{DB} = \frac{\sin\angle DBA}{AD}$$

i.e.
$$\sin\alpha = \frac{50 \times \sin 45^\circ}{300} = 0{\cdot}1178$$

$$\therefore \quad \alpha = 6^\circ\, 46'$$

i.e. required angle of drift is 6° 46′.

The aircraft must be set heading 6° 46′ into the wind, that is 6° 46′ north of east. The wind will then carry the aircraft along the line *AB*.

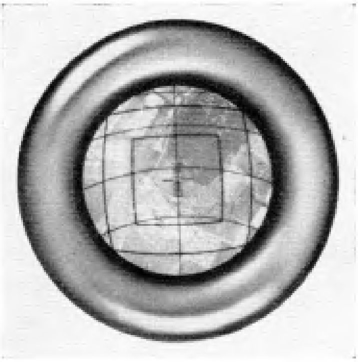
If the camera remains aligned so that two sides of the format are parallel with the fore and aft axis of the aeroplane, then the areas of ground covered by each successive photograph would overlap one another as in Fig. 4.8. This phenomenon is known as *crabbing*. From Fig. 4.8 it can be seen that crabbing gives rise to loss of stereoscopic cover, since the area of overlap between two consecutive photographs is reduced. The base line is no longer parallel with the format sides, and the angle between the base line and the format sides is known as *the angle of crab*. This is offset by turning the camera through the appropriate angle about its vertical axis. This angle will be equal and opposite to that through which the heading was turned; it is sometimes referred to as the *drift ring setting*, and will be 6° 46′ in a clockwise direction, or + 6° 46′, in the example just illustrated.

Since both speed and direction of the wind vary according to the height above ground, there is no way of calculating the angle of drift and the drift ring setting until flying height is achieved. Thus as soon as the required altitude is reached, the pilot will make a trial run over part of the ground which is to be covered in the first strip. He will fly so that the track of the aircraft passes directly over his prearranged navigation points. This heading angle will be checked by the navigator in the viewfinder. When the track is correct, the navigator will turn the viewfinder (see Fig. 4.9) until the navigation objects appear to travel parallel with the side of the format. The viewfinder is actually part of a modern air camera, so that the latter moves with the viewfinder. Thus the drift ring setting is achieved. With the older cameras it may be necessary to calculate the angle of drift after correct flying height is reached and after wind speed and direction have been measured.

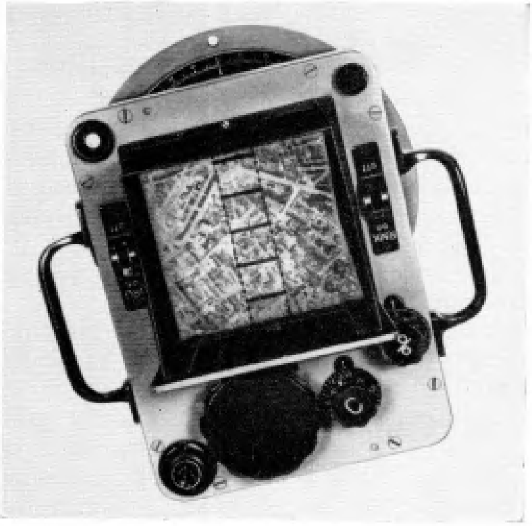
Trimming the camera for levels is by reference to spirit bubbles attached to the camera.

5. Tilt. As will be seen in Chapter 5, the assumptions made when using simple plotting procedures depend on the fact that the plumb point and the isocentre are very close to the principal point. In other words the photograph must be very nearly vertical. Specifications for flying for air cover will usually include a clause to the effect that tilt of any single photograph must not exceed say 3°; relative tilt between any two consecutive photographs must not exceed 5°; the average tilt of photographs included in the sortie must not exceed 1°. A maximum tilt of 2½° or even 2° for a single photograph is now possible, and the specifications are likely to be more demanding in the future.

However skilful the flying, and however stable the flying conditions, it is unlikely that perfectly vertical photography will be achieved. However, if, due to the incidence of the wind or for some other reason, the aircraft is not flying on a perfectly even keel, then the camera can be " trimmed for levels " by turning it about each of the horizontal axes in turn. Such trimming would normally be done again for each strip, especially where the unevenness of keel is due to a constant wind.



(*Wild Heerbrugg Ltd.*)



(*Zeiss Aerotopo*)

FIG. 4.9. VIEWFINDERS

The importance of maintaining direction throughout each strip can be realized when it is stated that a 1° deviation from course would result in a ground error of 0·17 km in a 10 km flying distance. If the lateral overlap were supposed to be 20 per cent with photography at a scale of 1/10,000, then the overlap on the ground would be only

$$\frac{230 \times 10{,}000}{1000 \times 1000} \times \frac{20}{100} = 0{\cdot}46 \text{ km}$$

Thus the error envisaged has already reduced the lateral overlap to less than a half its correct amount, and we have not yet considered the possibility of error in the overlapping strip.

Modern aids have made navigation a much more certain affair, and some of these are described below.

## SOME AIDS TO AIR NAVIGATION

The main problems of the air-crew are those of maintaining—

1. direction of aircraft relative to the ground;
2. (i) orientation of the camera relative to the aircraft, and
   (ii) the exposure interval;
3. verticality of the camera axis;
4. constant known flying height.

The alternative to direct viewing of a predetermined route on the ground involves some form of radar. Two main systems are in use with survey aircraft: Shoran and Decca. Both involve accurate fixing of two or more ground stations before flying can be undertaken.

A modification of the Tellurometer is sometimes used in the same way, and its extra accuracy in distance measurement enables ground Trig. stations to be fixed from the air. The equipment used for this purpose is known as Aerodist.

Another use for radar is found by coupling it with the Doppler principle. The latter is usually illustrated by reference to the change in sound as an express train rushes past. As the train comes towards you, the time taken for the sound waves to reach your ear gradually lessens, so that the time between successive waves is reduced, i.e. the frequency is increased, and the pitch is therefore higher; whereas as the train recedes the frequency is reduced. The same effect is obtained with radar waves. If a radar beam from the aircraft is directed towards the ground, the frequency of the reflected rays as received at the aircraft will be a measure of the speed of the aircraft relative to the ground. In practice four such narrow beams are used, and, if properly correlated with information from other instruments, the continuous measurement of velocity can be used to give deviation from course and camera position.

A modern commercial air survey firm would make use of these developments, e.g. Aero Service Corporation of Philadelphia use Shoran, Doppler and APR equipment, and among their aircraft are B–17's and P–38's which are capable of flying as high as 12,000 m.

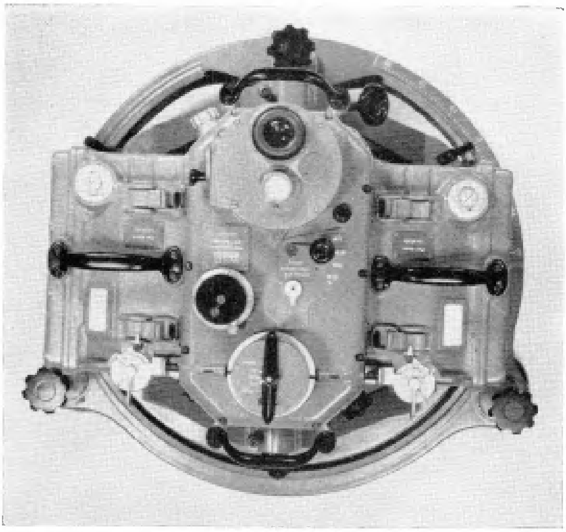
Modern cameras are provided with built-in viewfinders, in which the operator can see the same area of ground as is being photographed, and that ground view will appear to travel across the viewfinder screen. This provides a check on the aircraft heading. The operator will also be provided with a plot (preferably photographic) of the flight lines. If the heading is correct, the principal point marked on the screen will appear to travel along the flight line. Crabbing is now removed by turning the camera in swing until the required flight line is parallel with the base line in the viewfinder (the " ladder " in the Zeiss viewfinder in Fig. 4.9).

The " rungs of the ladder " in the Zeiss instrument or the curved lines in the Wild instrument are made to travel across the viewfinder screen in the direction of flight. The operator can adjust the speed of this movement until the lines keep pace with the apparent movement of the ground. The shutter mechanism is so correlated with this movement that the interval between exposures will be correct for the specified fore and aft overlap. The latter is preset on the instrument to the required value. Figure 4.10 (i) shows the controls for an RC7 camera and Fig. 4.10 (ii) shows it mounted in an aeroplane with an operator at the controls.

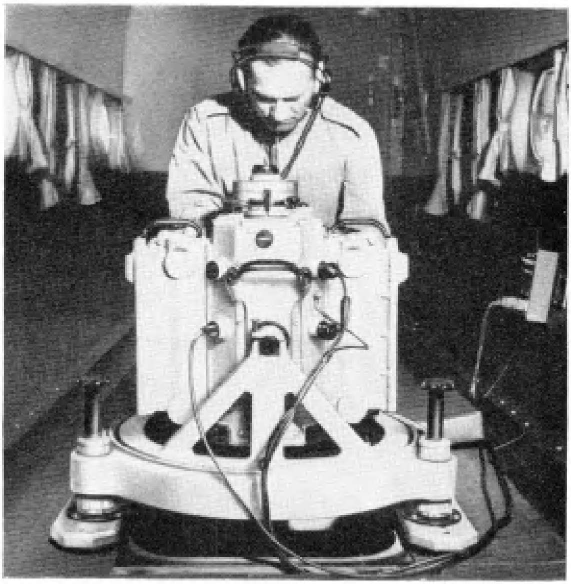
Acceleration forces of earth and aircraft prevent the straightforward use of a gyroscope in establishing verticality of the camera axis. Much research has been done in this field, and the Aeroflex Corporation of New York now produce a stabilized platform (see Fig. 4.11) incorporating a double gimbal mounting for the camera. The manufacturers quote a probable error of 25′. Aeroflex have recently designed an inertial platform which provides a vertical reference, though not true verticality, to within 3′.

It is perhaps a little easier to measure the amount of tilt present at exposure. The two best-known methods are by the Santoni Solar Periscope and the horizon camera. In the first, a " solar camera " records the sun's direction with respect to the camera axis and heading; from this the instrument computes and records the tilt components.

The horizon camera is fixed with its axis perpendicular to that of the main camera, i.e. its axis is approximately horizontal. In the best systems there are two horizon cameras fixed in such a way that



(i) Plan View of Wild RC7 Plate Camera



(ii) RC7 Camera Mounted in an Aeroplane
(*Wild Heerbrugg Ltd.*)

Fig. 4.10

the three camera axes are mutually perpendicular, and one of the horizon cameras points in the direction of flight. All three cameras are synchronized for simultaneous exposure. Figure 4.12 is a sketch diagram of two successive exposures of the fore and aft camera. Two image points, *a* and *b*, are chosen so that they can be accurately recognized on both photographs, and so that they are as far apart as possible. Collimating marks on each photograph will enable the axes to be drawn in as shown. The perpendicular distances, $a_1$, $b_1$, $a_2$ and $b_2$ are measured and their differences, $a_1 - a_2 = p_a$ and $b_1 - b_2 = p_b$, are determined. This may be done by turning each print through 90°, viewing stereoscopically, and finding the

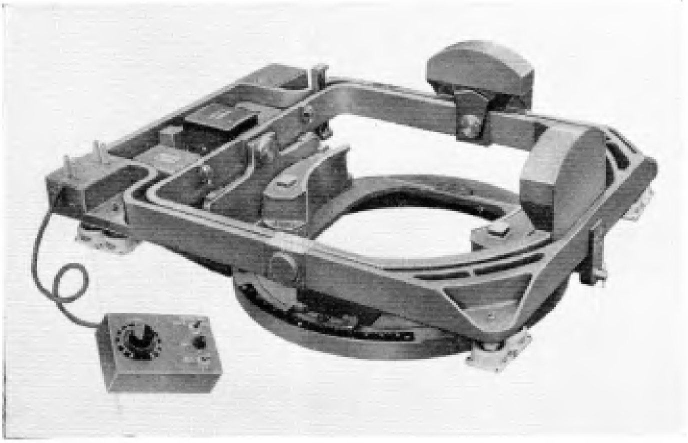


FIG. 4.11. STABILIZED PLATFORM
(*Aeroflex Laboratories Incorporated*)

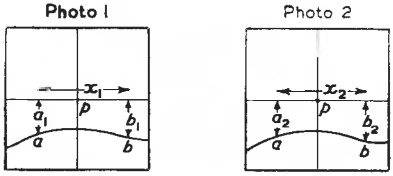


FIG. 4.12. SKETCH DIAGRAM OF SUCCESSIVE HORIZON EXPOSURES

parallaxes, $p_a$ and $p_b$, by the method described in Chapter 6, (the parallax of the $x$-axis being zero). From the diagram—

$$\text{relative lateral tilt} = \frac{p_a - p_b}{\frac{1}{2}(x_1 + x_2)} \text{ in radians, and}$$

$$\text{relative fore and aft tilt} = \frac{\frac{1}{2}(p_a + p_b)}{f} \text{ in radians}$$

($f$ = principal distance of the horizon camera).

The use of the second horizon camera allows a further determination of both components, and therefore gives greater accuracy. In practice this method has been found to give accuracies within 2′.

The flying height of an aircraft above datum is normally determined by barometric altimeter. Air pressure is subject to many variations, and the aircraft height can be only approximately measured by this method. The best accuracy which can be expected is of the order of 1·2 per cent of the flying height.

A statoscope is an instrument for measuring small differences in flying height. Essentially it comprises a barometer of very high sensitivity. It is capable of recording height differences as small as 300 mm, but it only operates over a limited range of altitude, and records only height differences from a particular isobaric surface. This surface is not flat, but in practice its height at any point is interpolated linearly between known heights at each end of a strip. The corrected altitudes can be expected to be accurate to within about 2 metres.

On the other hand, the aircraft's vertical clearance of the ground can be measured by a narrow radar beam. This beam is maintained nearly vertical by means of a gyroscope, and the distance to the ground is measured by recording the time taken for the beam to be reflected back to the aircraft from the ground surface.

If the ground clearances and the statoscope altitudes are both continuously recorded in graph form, then the difference between these two graphs will be a record of ground heights above datum. Instruments recording such data are known as Airborne Profile Recorders (more usually shortened to APR).

APR profiles are flown in conjunction with each strip of photography, so that the profiles can be related to each principal point. In order to obtain ground heights in positions suitable for the pass points of Chapter 5, intermediate profiles parallel with the flight lines are also flown, and some profiles are required in the transverse direction. This network will give sufficiently accurate height control for the contouring of small- and medium-scale topographic maps by air survey methods.

With normal strip photography as practised today, the plumb points are regularly spaced in the fore and aft directions, but they bear no such relationship to plumb points of the adjacent strips. As will be seen from Chapters 5 and 6, this is inconvenient and wasteful of control points. Modern methods of navigation make it possible to fly " bloc photography " in which the plotted positions of the principal points lie nearly at the intersections of a rectangular grid (see Fig. 4.13).

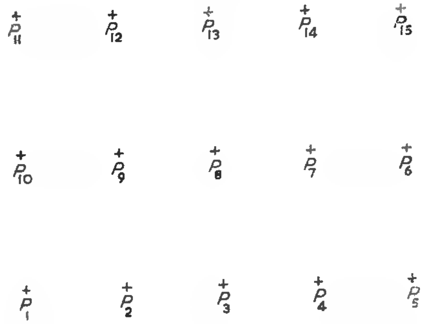


FIG. 4.13. BLOC PHOTOGRAPHY—THE SLOTTED TEMPLET PLOT (Compare Fig. 5.10)

The mechanism controlling the time between successive exposures is often referred to as the intervalometer, and the setting is calculated as follows—

$$\text{Scale of photography} = 1/20{,}000$$

$\therefore$ Ground distance between exposures

$$= 40\% \text{ of } 230 \text{ mm multiplied by scale factor}$$

$$= 230 \times \frac{40}{100} \times \frac{20{,}000}{1{,}000} = 1{,}840 \text{ m}$$

$$\text{Speed of plane, say } 300 \text{ km/h} = \frac{300 \times 1{,}000}{60 \times 60} \simeq 83 \text{ m/s}$$

$$\therefore \text{ Time interval} = \frac{1{,}840}{83} \simeq 22 \text{ sec}$$

The calculation would not be needed with modern cameras and viewfinders.

Convergent photography is also sometimes used in air surveys. Two exposures are made simultaneously: one camera pointing slightly forwards and the other slightly backwards. Each of the resulting photographs overlaps by about 100 per cent with one of the photographs taken from adjacent camera stations.

## FURTHER READING

(i) Schwidefsky, SURVEY AIRCRAFT pages 142–3, NAVIGATION 139–42, the STATOSCOPE pages 122–3, APR page 126, SUN PERISCOPE page 127.

(ii) *Manual of Photogrammetry*, Vol. I, Chapter 5.

(iii) Hart, pages 122–35.

(iv) Moffitt, Chapter 4.

(v) Hammond.

(vi) Cimerman and Tomasegovic.

There is a comprehensive review of methods of FLYING FOR COVER in the following article—

> CORTEN, F. L. (I.T.C., Delft), "Survey navigation and determination of camera orientation," *Photogrammetria*, XVI, No. 4 Special Congress No. C (1959–60).

In addition, *Electronic Surveying and Mapping* by Simo Lawila and published by The Ohio State University gives full information concerning ELECTRONIC NAVIGATIONAL AIDS.

(See Bibliography (page 346) for full titles.)