STEREO VISION, STEREOMODEL, AND STEREOSCOPES

For deriving maximum benefit from photographs they are normally studies stereoscopically. A pair of photographs taken from two camera stations but covering some common area constitutes a stereoscopic pair which when viewed in a certain manner gives an impression as if a three dimensional model of the common area is being seen (Fig.14). The basis of this subjective impression is dealt in the end of this lesson.

Depth Perception

Human beings can distinguish depth instinctively. However, there are many aids to depth perception, for instance, closer objects partly cover distant objects or distant objects appear smaller than similar objects nearby. These aids apply to monocular vision. For short distances binocular vision is more important and is of interest to Photogrammetrists, for it is binocular vision which enables us to obtain a spatial impression of a MODEL formed by two photographs of an object (or objects) taken from different view points.

Normally, our eyes give us two slightly different views, which are fused physiologically by the brain, and result in a sensation of seeing a model having three dimensions. This three-dimensional effect, due to binocular vision, is very limited however, decreasing rapidly beyond a viewing distance of one metre. Thus it may be concluded that binocular vision is primarily an aid in controlling and directing the movements of one's limbs.

A small percentage of the people do not have the facility of binocular vision and no amount of training will give it to them. Unfortunately, there is no known physical aid to provide stereoscopic sight to such person who does not possess it naturally, but training can help those having weak fusion.

Requirements of Stereoscopic Photographs

If, instead of looking at the original scene, we observe photos of that scene taken from two different view points, we can, under suitable conditions, obtain a three dimensional impression from the two dimensional photos. This impression may be very similar to the impression given by the original scene, but in practice this is rarely so.

In order to produce a spatial model, the two photographs of a scene must fulfill certain conditions:

a) The camera (spatial) axes should be approximately in one plane, though the eyes can accommodate the difference to a limited degree.

b) The ratio B/H, in which B is the distance between the exposure stations and H is the distance between an object point and the line joining the two stations, must have an appropriate value. In aerial photogrammetry this ratio is called the base-height ratio.

If this ratio is too small say smaller than 0.02, we can obtain a fusion of the two pictures, but the depth impression will not be stronger than if only one photograph was used. The ideal value of B/H is not known, but is probably not far from 0.25. In photogrammetry, values upto 2 are used, although depending on the object, sometimes much greater values may be appropriated.

c) The scale of the two photographs should be approximately the same. Difference upto 15% may, however, be successfully accommodated. For continuous observation and measurements, differences greater than 5% may be disadvantageous.

d) Each photograph of the pair should be viewed by one eye only, i.e., each eye should have a different view of the common overlay area.

The brightness of both the photographs should be similar.

Such a pair of photograph is known as stereoscopic pair or stereogram.

Stereoscopic vertical photography is the most commonly used one in aerial survey. The terrain is covered with strips of photographs. Overlap between two photographs in the same strip varies from 55 to 90%. Overlap of adjacent strips varies from 5 to 55%. The most usual overlaps are, in the strip, 60% and between two adjacent strips, 25%.

Binocular Observation of Stereoscopic Photographs

Accommodation and convergence

If we have a pair of stereoscopic photographs in front of us, on paper, glass plates or projected with projectors and they are oriented in such a way that epipolar lines are situated in the way described before we can observe them in different ways.

In order to evaluate the different ways of observation, we have to use the terms accommodation and convergence.

Accommodation refers to focussing of eye-lens to see objects sharply at different distances. An un-accommodated eye is considered to be focussed at infinity.

Convergence refers to the directing of lines of sight (i.e., the optical axes) of the two eyes to the same point. The optical axis of the eye can be changed in direction by rotating the eye in its socket. The angle the eye base subtends at the point is called angle of convergence or parallactic angle.

Normal reading distance is 250 mm, i.e., while reading we accommodate and converge the eyes at this distance. As the eye-base is one an average about 65 mm (2.5 inches) for human eye, the angle of convergence them is approximately 16 degrees. (The line joining the nodes of the eyes is called eye-base or the interocular or interpupillary distance (Fig. 15).

The relation between the accommodation distance (d) and angle of convergence (in radians) is given by

$$= \frac{E}{d}$$

E being the interpupillary distance

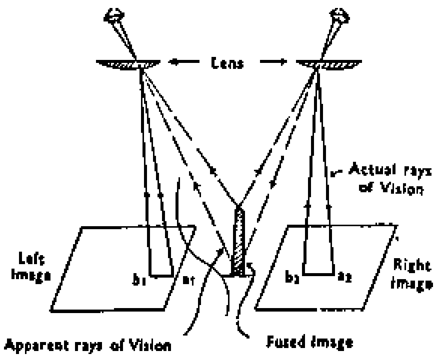

Fig. 14

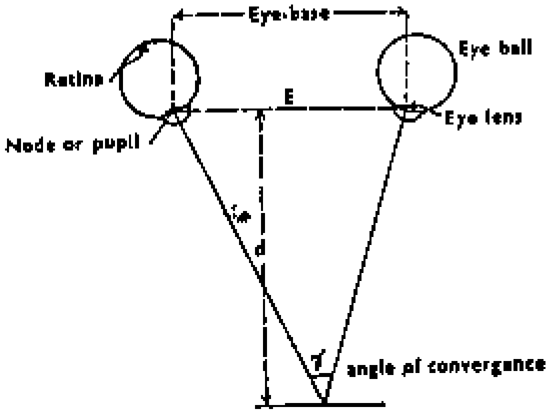

Fig. 15

Normally accommodation and convergence are automatically linked up. If we look at a point at a certain distance, accommodation and convergence are set for that distance. We can disconnect this link but not without much strain on eyes. A lot of practice is required for accommodation at a distance other than the distance of convergence.

There are three ways of observation of stereoscopic photographs:

a) Observation with Crossed eye axes

This involves looking with the right eye at the left photograph and with the left eye at the right photograph (Fig. 16(a). The convergence and accommodation are at two different distances, and this type of observation is, therefore, very tiring. Large photographs can be used conveniently by this method, but due to strain on the eye, this method is not used in practice.

b) Observation with parallel eye axes

This method is possible without any optical aids, but is tiring as well as the eyes are converged on infinity, yet accommodating at approximately 250 mm (Fig. 16(b). It is less tiresome if positive lenses are placed between the eyes and the photographs so that the photos are placed at the focal length of the lenses. The accommodation then corresponds with the convergence and the eyes are viewing naturally. The `pocket-stereoscope' was developed on this principle.

c) Observation with convergent eye-axes

When the accommodation and convergence are at the same distance the viewing is least tiring and this is the normal method of viewing. But in order to view the photos stereoscopically they must be superimposed, such that the point A and the corresponding point A' on the other photo lie at the point of convergence (Fig.16(c).

The images have to be separated so that left eye sees only the left hand photographs and the right eye only the right hand photograph. The resulting stereoscopic perception is similar to that of normal 3 dimensional perception. The separation may be achieved by colour filters or by polarized filters.

There is an interesting phenomenon in Stereoscopy. In viewing terrain in aerial photography a reversal of the relief is sometimes obtained by the eyes. Such a phenomenon is known as pseudoscopic illusion or Pseudoscopy. Such an impression can be obtained by viewing the photos with crossed eye axes. Sometimes, viewing with the shadows in case of excessive relief (e.g. hills) away from the observer can also result in pseudoscopy. So, in the initial stages, to avoid pseudoscopic view, it is desirable to view the photographs with shadows of objects falling towards the observer.

Separation by colour filters

The photos are either projected or printed in two different colours. By placing a filter of the same colour over each eye corresponding picture is observed by one eye only. In practice this problem is difficult to solve completely. The human eye is sensitive for light with wavelength from 400 to 720 millimicrons (mu). Fig. 17 shows the spectral sensitivity curve of eye. The vertex lies at about 560 mu.

A possibility for separation of the two superimposed images would be to use filters of which one cuts off all wave length over 560 mu (its colour would be blue-green) and the other all under 560 mu (orange-red).

The image projected in orange-red can be observed with an orange-red glass in front of the eye. With the blue-green image it is just opposite. This means, we have on one of our retina at bluish image from one projector, and on the other a red one from the other projector. We seem to be able to fuse these different images to one stereoscopic white-black image.

In the case of anaglyphs printed on paper the condition is different from that described above. The two images are printed in red and blue. The eye covered with the red filter sees both the red image is indistinguishable and only the blue image is visible as varying shades of gray. Similarly the eye covered with the blue filter seems the red image only. If the spectacles are reversed, we see the LH photograph with the right eye and vice versa. A pseudoscopic image will result.

Separation by polarized filters

Light has the characteristics of a wave motion in which the waves vibrate in all possible planes perpendicular to the direction of prorogation. These are called transverse waves. It is possible to analyze the transverse waves into separate components along two axes perpendicular to each other and to the direction of propagation by means of filters.

For stereoscopic vision the filters are placed so that polarized light rays forming the left image are at right angles to the light rays forming the right image. There are several advantages in using polarized light :

- light loss is about 50% only in both projections,
- there is not colour contrast between the two picture, and
- it is possible to use colour photography on this principle.

However, there is one big disadvantage in using the method, which has so far prevented its use in photogrammetry. With the type of plotting instrument, which uses this system, it is important, that the screen on which the image is projected be diffuse, so that it can be viewed equally well from all directions but a diffuse surface acts as a depolarizer and so no stereoscopic image would be apparent.

STEREOSCOPES

The function of a stereoscope is to deflect normally converging lines-of-sight so that each eye views a different photographic image.

Stereoscopes are grouped into 2 basic types :

i) Lens stereoscopes
ii) Mirror prism stereoscopes

Pocket Stereoscope

By far the most popular is the lens stereoscope commonly known as pocket stereoscope. The pocket stereoscope usually has plane-convex lens, upper side flat with a focal length of 100 mm. The rays entering the eyes are now parallel and converge at infinity and have been accommodated (focussed) at 100 mm distance (Fig. 18). Since the normal viewing distance is 250 mm, a closer view., i.e. at 100 mm result in a magnification. The magnification is then 250/100 = 2.5. More expensive types have a changeable eye base. Such a refinement is not necessary for operators with an average eye-base range of 60 to 68 mm. The pocket stereoscope is cheap, transportable, and has a large field of view. It has two big disadvantages:

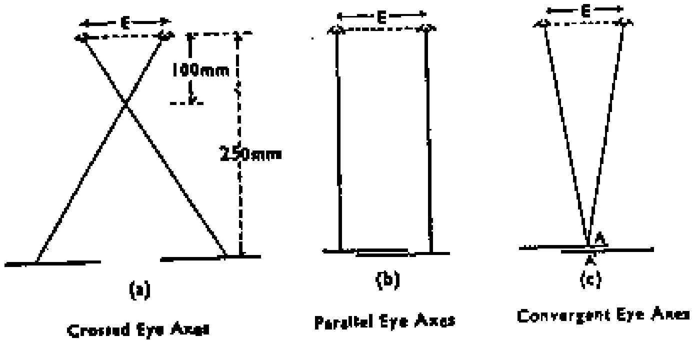

Fig. 16

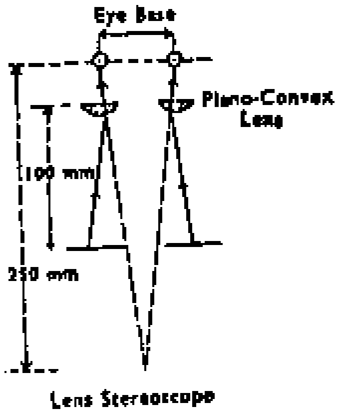

Fig. 18

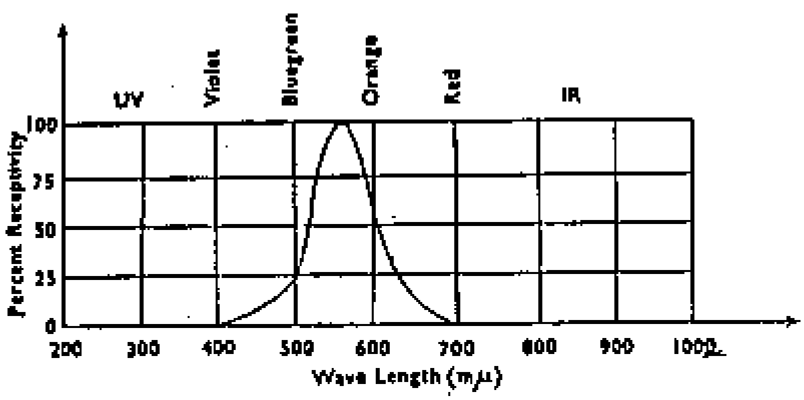

Fig. 17

a) Limited magnification. Pocket stereoscopes with more than three times magnification cannot be equipped with simple plane-convex lenses, due to the too large an increase in lens aberrations. In addition the distance between the head and the photos becomes to small for adequate illumination without undue complications.

b) The distance between corresponding points on the photos must be equal to or smaller than the eye base. With normal size photographs this becomes difficult or impossible without bending or folding the photos.

It should not be forgotten, however, that due to the simple optical system the image quality of the pocket stereoscope is very good.

Mirror Stereoscope

The two above mentioned drawbacks have led to the development of the mirror stereoscope. The normal size photos (23 cm x 23 cm) can be separated and seen under the stereoscope without folding them. The path of the bundle of rays has been diverted and brought to the eyes at 65 mm separation. This is achieved by reflecting mirrors. Normally the distance between corresponding points is kept at 240 mm so that photographs are placed separately, i.e., it effectively increases the eye base from 65 mm to 240 mm. As in pocket stereoscope the picture must be at the focal plane of the lenses in order to have convergence at infinity. The mirrors M1 are placed in such a way that the picture distance via the small mirrors M2 (generally prisms) become equal to the focal length of the lens, usually 300 mm (Fig. 19(a). This gives approximately 250/300 = 0.8 x magnification, or rather reduction the picture observed. to magnify the image additional oculars of magnification 3x to 8x can be used over the prisms or a lens placed before each prism (See Fig. 19(b) giving a magnification of about 1.8x.

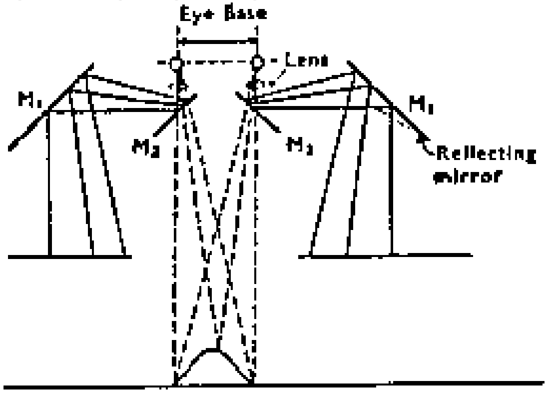

Fig. 19 (a)

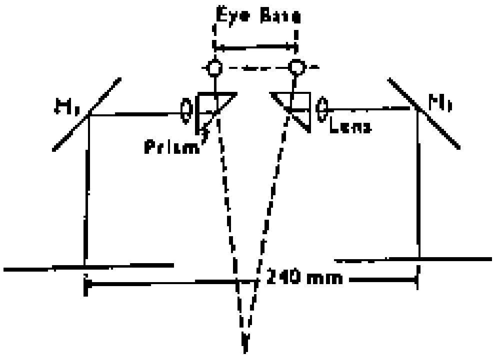

Fig. 19(b)

SUBJECTIVE SPATIAL MODEL

The subjective spatial model observed with a stereoscope when photographs having overlap are viewed is termed as Stereo-model. If one observes the ground from an aeroplane one does not see a spatial model. The eye base is so small (65 mm average) compared with the flying height of the aeroplane that the two-retine image is virtually the same. Therefore, there is no true comparison between the natural view and the stereoscopic view of a model.

It may be assumed that we see natural relief if we observe an object with a normal base-height ratio. In the light of what has been said before, i.e. that binocular vision was mainly an aid in controlling the movements of the limbs, we could say that a normal base-height ratio is near about 65/250, i.e. about 1/4 to 1:1 or even 1:0.6, this could lead to the conclusion that the stereoscopic image formed by aerial photographs is always different and distorted. However, there are other factors, which influence the subjective model.

Assume that the photographs are taken with a vertical optical axis and that they are observed flat on a table, oriented according to the epipolar rays.

a) The first difference is that the eye-base has been changed from say 800 mm to 65 mm. This change only alters the scale of the model and the two views remain similar in every other respect.

b) The second difference is that the photographs are observed at a distance, which is not equal to the principal distance. This, not only, alters the magnification of the model but simultaneously alters the ratio between the x, y scales against the z scale. We get an affine flattened model if this distance is smaller than the principal distance and exaggerated if it is greater than the principal distance. This corresponds with what one finds in practice.

c) The third difference is that our eyes are moved away from the vertical through the principal points. This produces deformations difficult to construct or visualize in a diagram.

d) The fourth difference is that one of the photographs is moved during observation, so that the corresponding points are seem vertically. This shift is equal to the stereoscopic parallax (P), and makes the rays from the corresponding points to the respective observation. However, this parallelism renders the construction of the spatial image impossible as it means that the spatial model should be formed at infinity. In practice the image does not appear at infinity but an indeterminate distance varying from 250 mm to 1 meter according to the personal idiosyncrasies of the operator.

e) Lastly the shape of the object, the shadows, the natural association of the observed data and relative distance all influence the process of depth perception.

MEASUREMENT OF HEIGHT FROM AERIAL PHOTOS, PARALLAX AND PARALLAX MEASUREMENT

Parallax

The feasibility of finding height differences of objects with the help of measurement on photographs of the area concerned is the most important quality of photographs.

This is achieved by measuring parallaxes on the photographs. What then is parallax ?

The term parallax is applied to the apparent change in the position of an object caused by change of position in the observer. The term is widely used in optics, astronomy and other sciences and has different significance in each case. In photogrammetry we are generally concerned with stereoscopic parallax. The aerial camera does not take aerial photographs continuously but takes them at certain exposure intervals. suppose instead of the negative film there was a ground glass on which ground images could be seen, then it will be seen on changing with respect to the camera frame.

Consider that at one instant the airplane is at 01, vertically above a point P. The image of P will appear at p on the ground-glass (Fig.20). After sometime when the plane is at 02, it will appear at p'. This shift pp' in the position of the image of P on the ground glass is the parallax of P. Similarly for any other point Q will be qq'.

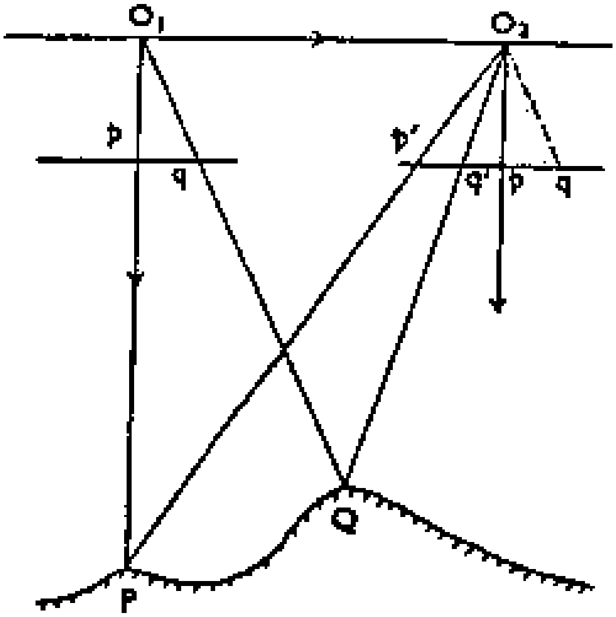

Fig. 20

Again it will be seen that images of the higher points in the terrain will move across the ground glass more rapidly than the images of lower points in the valley. Thus the separation (Parallax) of the images of a higher point would be more than the separation (parallax) of lower points (during the same interval of time). That means, points at higher elevation exhibit a greater parallax than those at the lower elevation.

X- and Y- Parallaxes

In Fig. 21, P1, p2' and p2 p1' are the photo bases of the left hand and right hand photographs respectively. a1 and a2 are the corresponding images of an object point A p1 a1 and p2 a2 can be resolved into two mutually perpendicular directions - one along the direction of flight (X-direction) and the other perpendicular to it (Y-direction). Then, if X1, Y1 and X2, Y2 are the resolved parts of p1 a1 and p2 a2 respectively in the two directions.

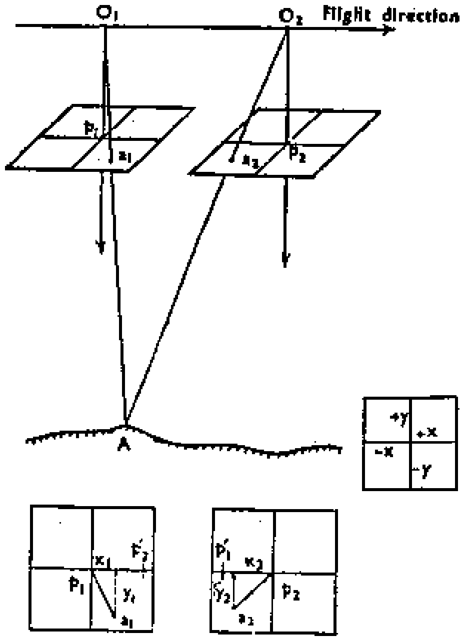

Fig. 21: Parallax of principal points

X1 - (-X2) = (X1 + X2) is the X- parallax or absolute stereoscopic parallax or horizontal parallax and is defined as the algebraic difference in the direction of the air base of the distances of the two images of an object from their respective principal points.

(Note:- Minus sign is given to X2 as the distance from the principal point is measure in the negative X-direction, i.e., opposite the flight direction).

Similarly (Y1 - Y2) is called Y-Parallax or Vertical Parallax. If the paired photographs are assumed to be vertical and taken from equal altitude above the datum, the Y-Parallax is absent.

Parallax of principal points

If we transfer the principal point P1 of the left hand photograph of a stereo pair on the right hand photograph at p1' (Fig. 21), then by definition p2 p1' is the parallax of principal point of the left photograph and is the distance between the exposure stations (air-base) on the scale of the right hand photograph.

Similarly, p1 p2' is the parallax of the principal point of the right hand photo and represents the air-base on the scale of the left hand photograph.

If the terrain is flat and flight is level and flight altitude does not change the scale of the two photos will be exactly same and hence the two photo-bases will be exactly equal.

It is, therefore, simple to find out the parallax of either of the principal points by measurements on the photographs, provided the assumption do not deviate much from ideal situation, viz.

i) focal length in both cases same, which is always the case
ii) flying height is the same
iii) optical axis vertical

In practice we tolerate tilts of about 3 degrees; of course, flying heights are within reasonable limits.

Parallax Difference

Assuming that there is no tilt and flight is level, two photographs are taken with image of an object point A a1 and a2 on them respectively. If the two photographs are put on top of the other with their principal point's p1 and p2 and flight direction in coincidence, then by definition a2 a1 is the absolute stereoscopic parallax (Fig. 22a).

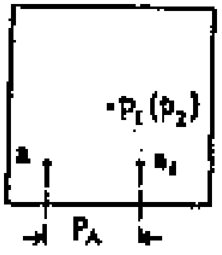

Fig. 22(a)

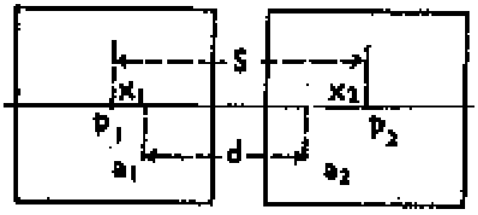

Fig. 22(b)

If now we put the pair of photographs under a stereoscope for fusion, they will have to be separated at a convenient distance p1p2 say a distance represented by `S' (Fig. 22b).

The parallax of A, $P_A = p_1 p_2 - a_1 a_2$

$= S - a_1 a_2$

Similarly parallax of another point Q,

$P_Q = S - q_1 q_2$

Considering `A' as the reference point, the parallax difference between `A' and `Q' is

$$\Delta p = P_Q - P_A$$
$$= a_1 a_2 - q_1 q_2$$

In practice, direct measurement of parallax is seldom done, instead we measure the parallax difference (Δ p) with the help of parallax bar or parallax wedge.

Generally, graduations on parallax bar are marked in such a way that if the separation between corresponding images decreases (i.e. `d' decreasing - Fig. 22b), the reading on parallax bar increases - the point with larger parallax gives a higher reading, and correspond to a point of higher elevation. In such a case the parallax difference

Δp = (Parallax bar reading for Q - Parallax bar reading for A)

= $q_1 q_2 - a_1 a_2$

Parallax Formula

Starting with the assumption that:

I. photographs are free from tilt,
II. the flight altitude above the datum remains unchanged,
III. the photographs are a central projections, with centre of projection at the perspective centre, i.e., there is no lens distortion,
IV. there is no distortion in the photographic material

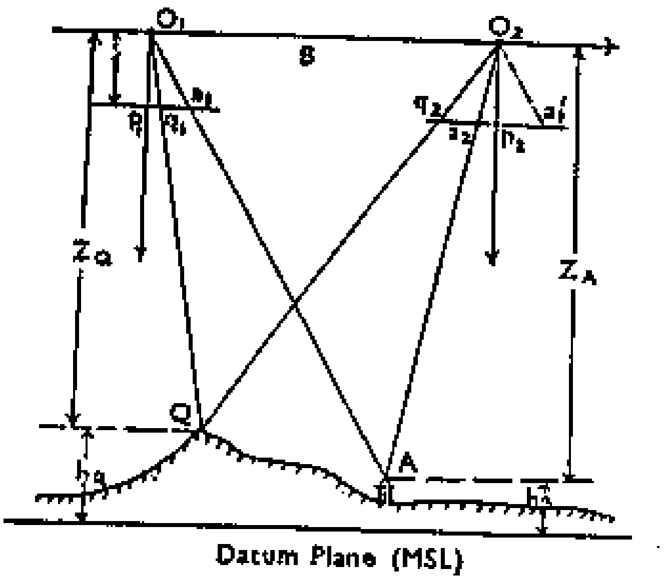

Fig. 23

We have from figure 23: O_1 and O_2 is the air-base B at a vertical distance of ZA and ZQ above terrain points A and Q respectively; a1 and a2 are the corresponding images of about points A on the photograph. Focal length of the aerial camera lens is f.

From O_2 draw a line O_2 a1' parallel to O_1 a1. Then, by definition parallax of A is :

$$PA = a2\,a1'$$

From similar triangles O_2 a2 a1' and A O_2 O_1

$$\frac{ZA}{f} = \frac{B}{a2a1'} = \frac{B}{PA}$$

$$ZA = \frac{B.f}{PA} \qquad ....(1)$$

Similarly for a point Q, $ZQ = \dfrac{B.f}{PQ}$ .... (2)

From equations (1) and (2)

$$ZA - ZQ = B.f\left(\frac{1}{PA} - \frac{1}{PQ}\right)$$

$$= B.f \, \frac{PQ - PA}{PA.PQ}$$

$$= \frac{B.f}{PA} \; . \; X \; \frac{PQ - PA}{PQ}$$

$$= ZA \, . \, \frac{PQ - PA}{PQ} \qquad \text{.... by substituting for } \frac{B.f}{PA} \text{ from equation(1)}$$

$$= ZA \, . \, \frac{\Delta p}{PA + \Delta p} \qquad \text{.............................}(3)$$

where $p = PQ - PA$

Let hA and hQ be the mean sea-level heights of object points A and Q respectively. Then

$ZA + hA$ = Flying height of the aircraft above datum plane (MSL)

= $ZQ + hQ$

$ZA - ZQ$ = $hQ - hA$

= differences of heights between terrain points Q and A

= h.

Equation (3) now can be written as

$$h = \frac{ZA. \, \Delta p}{PA + p} \qquad \text{.....................}(4)$$

Relation (4) is the fundamental parallax equation.

Equation (4) can be put in the form (by cross-multiplying and rearranging)

$$PA \; . \; h$$

$$\Delta p = \frac{\quad}{ZA - h} \qquad \ldots\ldots\ldots\ldots(5)$$

We have assumed that these parallax equations (equations (4) and (5) are valid only when the photography is vertical and the flight is level. However, it may be applied for small variations from these ideal conditions. If h values are small (e.g. height of tree, embankment), the simplified formulae

$$h = \frac{ZA \, . \, \Delta p}{PA}$$

can be used and similarly

$$\Delta p = \frac{PA \, . \, h}{ZA}$$

For reasons of convenience for the absolute parallax of the principal point of the left hand photograph (PA) the length of photo-base on right hand photograph, is commonly measured and substituted in the solution of parallax equations. For near vertical photographs or relatively flat terrain, the use of average photo-base of the stereo-pair gives reasonably accurate results. For formulae then become

$$h = \frac{Z \, . \, \Delta p}{bm + p} \quad \text{and} \quad \Delta p = \frac{bm \, . \, h}{Z - h}$$

and the approximate formulae can be written as

$$h = \frac{Z}{bm} . \, p \quad \text{and} \quad \Delta p = \frac{bm}{Z} \, . \, h$$

Where Z is the average flying height above the terrain and bm the average photo-base.

Image displacement due to tilt of any one of the two photographs causes false parallax across the overlap. Similarly the slope of the air base affects the parallaxes. As such the parallaxes observed on such photographs are burdened with errors. For the two points, between which the height difference is required, if not far from each other, the effect on parallax due to tilt and inclination of air base is nearly the same and will cancel each other.

Floating Marks

Floating marks are also known as the Measuring marks as these are used for precise measurement on stereo photographs. These are defined as pairs of identical reference marks when viewed stereoscopically in conjunction with a photographic overlap combine to form a single floating image.

If we put two dots, A1, A2 (Fig. 24) about a mm in diameter at a distance of about 65 mm on a piece of paper and see them under a pocket stereoscope (the eye base kept parallel to the line joining the dots), they will fuse into one dot. Now if we put another set of dots B1, B2 close to them and such that the line joining them is parallel to the eye base and spaced closer than the first set and seen under stereoscope, we find that this set also fuses into one mark, but floating i.e. higher above the first one. The vertical distance `AB' is known as stereoscopic depth. That means if the mark has a different parallax from that of its surroundings, it will appear higher or lower. But if no parallax exists between the dots and the object images, the fused dot appears in contact with the fused image. At this moment quite accurate measurement may be made of the distance between these reference marks.

Measurement of Parallax Difference

Parallax difference can be measured with ordinary ruler but it cannot give accurate/precise results. For accurate results the principle of floating marks is used in parallax bar or parallax wedge Thus the function of these stereo meters is to measure changes in parallax that are too small to be determined with the ordinary rulers.

Parallax bar

A parallax bar consists of two glass plates, A and B, engraved with identical measuring marks, connected by a bar (Fig. 25). The separation S between the marks can be changed by a micrometer screw. M, graduated so as to give reading upto 0.01 mm. Glass A can be shifted along the rod and can be clamped by screw C. Graduation on the bar are arbitrary and do not refer to the actual separation S of the measuring marks. The graduations on the micrometer and the bar are usually numbered increasingly as the distance between corresponding points, i.e., the separation S, is decreasing.

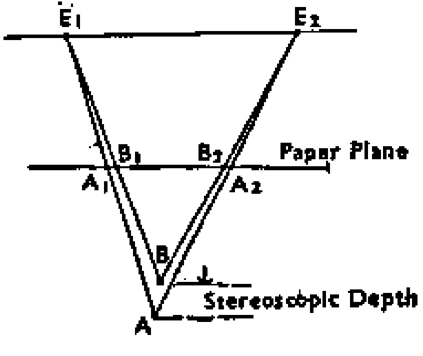

Fig. 24

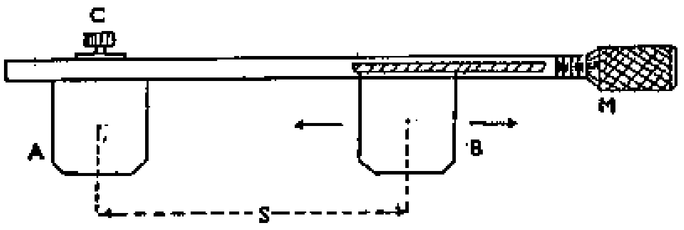

Fig. 25

Parallax wedge

This is a sheet of transparent material with no converging rows of dots. The wedge is slid backwards and forwards in `Y' direction until two dots fuse as one dot on the ground, the reading then being noted. The dots are numbered in accordance with corresponding parallax values. (Fig. 26).

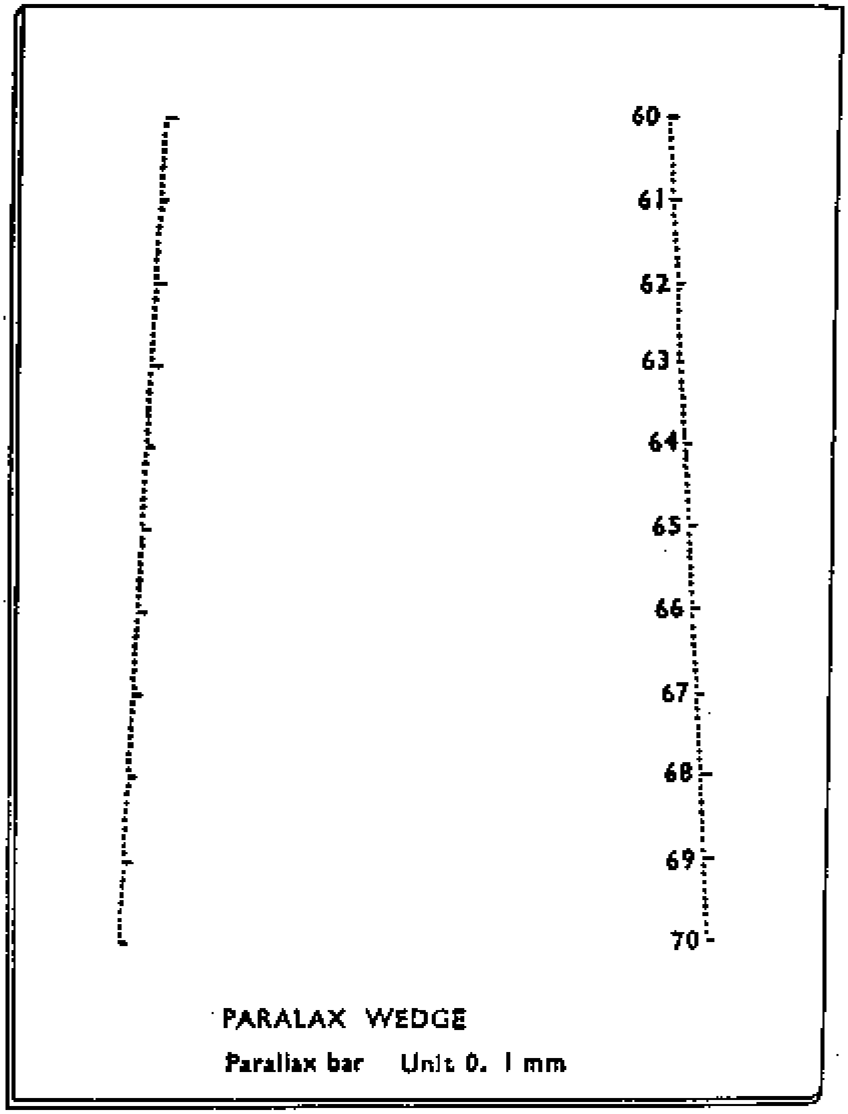

Fig. 26

STEREO IMAGES FROM SATELLITES

Stereo images can be obtained from satellites also in the same way as the are collected from an aircraft, and the study is called as satellite photogrammetry or satellitegrammetry. In case of stereo photography from satellites the basic mathematical and geometrical aspects remain same as in aerial photogrammetry. However in case of satellite photogrammetry, the flying height is of order of some hundreds of kilometers in comparison with, a few kilometers, in aerial photogrammetry. As a result of this, the earth's curvature plays more than usual role in geometry. The ratio of earth's relief with flying height also becomes too small in satellite photogrammetry, thus seriously effecting the perception of relief in stereo images, obtained from satellites. Cameras as well as scanners have been used in satellites to obtain stereo images. During early stages of manned and unmanned satellite missions, small 70mm cameras were used to take photographs, at very small scale and low resolution. Later, attempts were made to obtain better stereo images from satellites using large format cameras and scanners, which are described, in the following sections.

STEREO IMAGES FROM LARGE FORMAT CAMERA

The Large Format Camera (LFC), a special purpose camera with high resolution and high geometric fidelity, was flown in NASA Space Shuttle mission in October 1984. The LFC in Space shuttle mission is a precision cartographic camera, with image format 230 X 460 mm and focal length 305 mm and advanced image motion compensation mechanism to account for the shuttle ground velocity of 27000 km per hour. The photographs were taken from varying flying height of 235 to 375 km above earth. Stereoscopic coverage was taken with variable overlap (20 to 80 percent) in the same way as in aerial photography. The photographs retained sharp details even after enlargement and were found to have high cartographic value. The original photos were at scale of 0.8 million to 1.2 million.

On another mission, a 230 X 230 mm format photogrammetric camera with 305 mm focal length lens was also used with a colour infrared film. The ground resolution was found to be of order of 25 meters.

Skylab, a manned satellite, carried an Earth Terrain Camera (ETC, S-190B Experiment) had a 457 mm focal length lens and acquired photographs with a ground coverage of 109 by 109 km. The photographs were collected in normal color, black and white and IR colour at a scale of 1:950,000on 11.4 cm square film. The overlap was 60 percent, which is well suited for photogrammetric purposes.

The satellite images taken from Russian Satellite during mid eighties, from a camera with focal length of one meter and ground resolution of about two meters are now available for the most part of world.

The photographs taken from satellites at altitude of few hundred kilometers on a photographic film are seriously effected by atmospheric haze. Therefore either color infrared, or panchromatic films are used with minus blue filter to cut the blue haze.

ACROSS TRACK SCANNERS FOR STEREO IMAGING

The common optical mechanical scanners, using a mirror, sweeping the small area (pixel) being viewed, across the flight path are known as Across Track Scanners (and also as whiskbroom scanners). The Multi Spectral Scanner (MSS) used in Landsat series of satellite comes under category. The orbit of Landsat and other similar satellites is such that, at equator adjoining images have about 14 percent overlap. This overlap increases towards Polar Regions to as much as 85 percent. In such areas of high overlaps, the two images taken from adjoining satellite path could be used as stereo images. The base to height ratio varies from 0.174 at the equator to 0.031 at polar regions. In such images obtained by across track scanners, the relief displacement is in cross track scan direction, (outwards from the center of the scan line in each scan line). However, due to limited ground resolution, and unsuitable base to height ratio, the relief perception is not suitable for cartographic application.

ALONG TRACK SCANNERS WITH STEERING CAPABLITY

The along track scanners are also known as pushbroom scanners. They consist of linear arrays of numerous Charge Coupled Device (CCD). High Resolution Visible (HRV) imaging system used in SPOT satellite series and PAN (a panchromatic camera) in IRS-1C satellite belong to these type. The satellites are provided with steering capability to tilt the sensor with an angle towards right or left. Thus, off nadir view could be obtained, covering the same area from a different orbit. The amount of tilt is variable to plan for a suitable look angle from available orbits to cover the area of interest. In these scanners also, the relief displacement is normal to the ground track. The stereo images are found to be suitable for medium scale mapping. Many researchers have found that SPOT image (PAN) with 10 meter resolution in stereoscopic mode, can be used for topographic mapping at 1:50,000 scale with 20 meter contour interval.

Geometry of PAN camera in IRS-1C Satellite

This uses reflective optics along with 4096-element CCD linear array (7 micron X 7 micron) for imaging. A special arrangement, comprising of an isosceles prism reflector, is used for covering full swath of 70 km. spatial resolution at nadir is 5.8m. The swath steering range is ñ 26 o, the step size of ñ 0.09 and the repeatability for stereo coverage is 0.1o. The data is collected in panchromatic mode having spectral band 0.50 μm to 0.75 μm. The space segment specifications are given in Table 1. PAN data is encoded in 6-bits.

Table-1. Space segment specifications of IRS-1C

Orbit type	Polar Sun synchronous
Altitude	817 km
Inclination	98.69o
Distance between adjacent traces	117.5 km
Repetivity for LISS-3	24 days
Repetivity for WIFS	5 days
Off-nadir coverage ñ 26o for PAN	398 km.
Stereo viewing capability	5 days

Geometry of HRV camera in SPOT Satellite series

SPOT pushbroom scanning system does not employ a scanning mirror, rather, it employs a linear array of CCDs arranged side by side along a line perpendicular to the satellite orbit track. The HRV contains four CCD subarrays of 6000 elements each, acquiring data in panchromatic mode to record 10m resolution data. Three 3000 element subarrays are employed in the multispectral mode at 20 m resolution. HRV optical system has a plane mirror, which can be rotated to either side by, ground command, through an angle of ñ 27o (in 45 steps of 0.6o each). This allows each instrument to image any point within a strip extending 475 km to either side of the satellite ground track. At latitude of 45o, there are six possible occasions during the 26-day orbit cycle on which successive day stereo coverage may b e obtained. At the equator, only two stereo viewing opportunities on successive days are possible. The base height ratio also varies with latitude from approximately 0.50 or 45° to approximately 0.75 at the equator. If stereoscopic coverage need not be acquired on successive day basis, the range of possible viewing geometry greatly increases. The specifications of the orbit of the satellite is given in Table 2.

Table-2. Orbital characteristics of SPOT series satellites

Altitude	832 km.
Orbital period (min)	101
Inclination (degrees)	98.7
Equatorial crossing time	10.30 AM (local sun time)
Sensors	HRV
Repetivity	26 days
Stereo viewing capability	5 days

ALONG TRACK SCANNER WITH FORE & AFT LOOKING

Some pushbroom scanners employed fore and aft looking mode with the help of external mirror to produce stereo images. This external mirror attachments provides forward looking and an aft looking channel in addition to the normal downward looking (nadir looking) channels. In Multispectral Electro-optical Imaging Scanner (MEIS II), which was developed for the Canada Centre for Remote Sensing, acquired data in eight spectral bands ranging from 0.39 μm to μm1.1 μm, with an IFOV of 0.7 mrad and a total field of view of 40o. This was the first airborne pushbroom scanner to be used operationally.

RADAR STEREO IMAGES

RADAR is acronym to Radio Detection And Ranging where microwave pulses are transmitted to illuminate the terrain and back-scattered pulses from the terrain are received to produce images of the terrain. The operating principle and other details are discussed separately in other sections. Stereo images can be acquired using Radar also in the same way as the across track scanners are used i.e. images are collected from two adjacent paths. However, because the Radar side lighting effect will be reversed on the two images of the stereo pair, stereoscopic viewing is little difficult using this technique. Radar can acquire stereo images by varying the flying height also, if it is airborne, or by having two antennae with two different look angles. There are so many other parameters are to be considered in reproducing stereo models from these type of Radar stereo pairs other than from photogrmammetric point of view. Measuring parallax and feature heights and the related study, from these images is called Radargrammetry. Among Space borne Radar systems, SIR-B and SIR-C, the space shuttle imaging Radars and RADRASAT, a Canadian satellite presently in the orbit, collected stereo images. SIR-B Radar experimental mission flown during October 1984, collected stereo images in L-band, HH polarization, with varying look angles from 150 to 60o. The azimuth resolution was 25 m and the range resolution varied from 14 m at a look angle of 60o to 46 m at a look angle of 150. SIR-C collected images in mutli-frequency, multi-polarization modes with varying look angles ranging from 15o to 55o. Radarsat SAR is a C-band system operating with HH polarization. The system can be operated in a variety of beam selection modes providing various swath widths, resolutions and look angles.

The Modular Optoelectronic Multispectral Scanner (MOMS) was developed in Germany and works like pushbroom scanner with linear array of CCD.

The size of actual ground swath covered varies with pointing angle employed. At the 27o maximum value, the swath width for each instrument is 80 km. When the two instruments are pointed so as to cover adjacent image fields at nadir, the total swath width is 117 km and the two fields overlap by 3 km. While each HRV instrument is capable of collecting panchromatic and multispectral data simultaneously, resulting in four data streams, only two data streams can be transmitted at one time. thus either panchromatic or multispectral data can be transmitted over a 117 km wide swath, but not both simultaneously.

TABLE 4 Salient features of Future SAR systems planned for launch after (1993)

MissionYear	Freq.	Pol.	Look angle (deg)	Swath (km)	Resolution (m)
SIR-C 1994 (USA/ GERMANY)	L, C & X-Bands	HH&VV HV&VH VV	15-55	15-90	30
ERS-2 1994 (EUROPE)	C-Band	VV	23.5	80	25
ALMAZ-2 (RUSSIA)	1996	--	--	--	--
RADARSAT (CANADA)	1995 C-Band	HH	20-40	100	25
			20-40	150	35
			37-49	45	10
			49-59	300/500	100
			49-59	75	30
EOS (USA)	1998 L, C & X-Bands	VV,HH	15-55	30-120	30
		HV&VH		700(Scan)	15
		HH&VV			
ENVISAT (EUROPE)	1998 C-Band	VV,HH	20-50	100-400	30