DEPARTMENT OF AGRICULTURAL ENGINEERING

PHOTOGRAMMETRY FOR AGRICULTURE

BRIAN DOUGLASS

Course Handbook 1

LINCOLN COLLEGE CANTERBURY NEW ZEALAND

PHOTOGRAMMETRY FOR AGRICULTURE

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An Introductory Handbook for Students and Field Officers

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PREFACE

Aerial photographs are relatively cheap, easy to use and are readily available. Used intelligently they save time, they are accurate and can be used in almost all types of land use survey and land classification. They are the most useful tool in land use survey work which modern technology has given us.

The purpose of this handbook is to assist students in gaining sufficient knowledge to use aerial photographs in the field. With a minimum of experience on the job they should be able to speed up their work and reduce the costs and labour of producing survey reports, programmes of development and designs for water control and conservation works.

Advanced photogrammetry is a complex mathematical science using very costly and sophisticated instruments but it is not necessary to know or understand such techniques to use air photos in the field. It is necessary, however, for the field officer to know his own limitations and the limitations of the relatively simple equipment he uses. When he does he will know when to hand over his task to draughtsmen and surveyors to complete and refine his ground work. In this day and age there is no point in struggling or making a crude job of a task which can be done better by someone more skilled. The problem is often to know how, when and what jobs to ask the expert to do and which jobs, where and why, you should do yourself.

It is hoped this handbook will take some of the mystery out of the use of air photos. There are few techniques which lend themselves so well to humbug.

Photogrammetry - the science of preparing topographic maps and making measurements on aerial photographs and photo-interpretation - the art of recognizing features on them - are not separate subjects and are mutually dependent. Agricultural field officers are primarily concerned with photo-interpretation which is a difficult subject to teach in a formal manner because it is best learnt by experience in the field. The photogrammetric techniques outlined herein comprise about the minimum necessary for field officers.

There are no original contributions to the subject in this handbook, nor is it in any way intended to be a substitute for the student texts available in libraries and on the bookstalls. The intention in preparing these notes and exercises has been to help students and field officers to avoid the unnecessary mistakes and inefficiencies I experienced using air photos as a field officer for some fifteen years.

Brian Douglass

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PROBLEMS

CHAPTER ONE
AERIAL PHOTOGRAPHS

1.0 The Uses of aerial photographs

Survey - photogrammetry is the basic science of modern mapmaking.

Inventory - record of areas and measurements of stock (particularly forest inventory)

Administration - detail of particular areas shown with easily recognised symbols, e.g. fence lines, road lines, flood boundaries, stream alignment, areas of gully erosion etc.

1.1 The advantages of aerial photographs

Low cost

Speed

Accuracy - where skilled draughtsmen are available.

Unskilled draughtsmen can interpret detail on the photographs which can then be transferred to accurate base plans.

1.2 The types of aerial photographs

Vertical

Low oblique (often includes the point vertically below the camera

High oblique (includes the horizon)

Continuous strip

Hand cameras

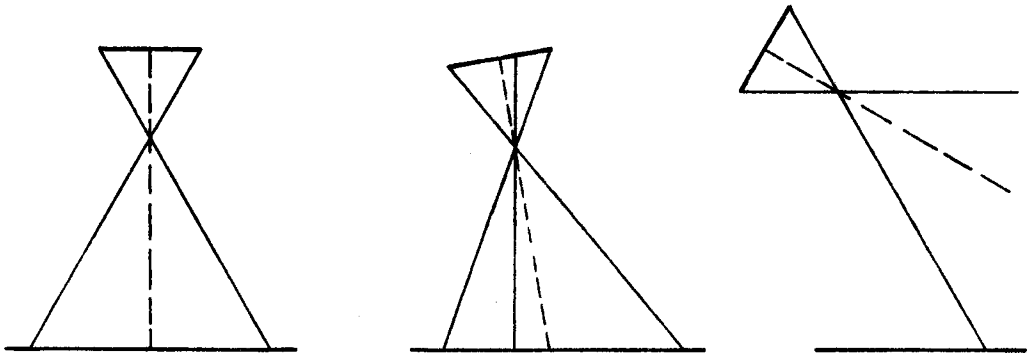


Figure 1.1

The vertical aerial photograph (1.11) is the type most frequently used and most readily available. The low oblique (1.12) and the high oblique (1.13) are only used now for special purposes such as military reconnaisance and forest inventory. Continuous strip photographs - where the speed of the shutter and film are adjusted to the flight speed of the aircraft - are similarly used only for special purposes of military reconnaisance and for sampling. The equipment, aircraft and process are very costly and expensive, and, to my knowledge, have not been used in New Zealand. The use of hand cameras or similar uncontrolled "snapshot" photography does occur and is a relatively cheap way of recording such things as the positions of tile drains where the excavation scars are still visible, the area planted or felled at any given date in forest operations, and before and after situations in erosion control. Such photographs can also be used to fill in gaps in systematic photographic cover. The "four point plot" method of transferring points from such photographs to the map is very laborious. Unless specially mentioned all further reference in this handbook to aerial photographs will mean vertical air photos, i.e. photographs taken with the axis of the camera truly perpendicular to the horizontal or with an angle of tilt of less than 4 degrees.

1.3 The types of print available

(a) Standard print - usually 7" x 7" or 9" x 9" or the older 9" x 7". These should be printed so that they are neither too contrasting nor too flat. With wide film they may be contact prints and while they are not always printed in this way - they do have a standard size.

(b) Ratioed prints - where the prints have been enlarged or reduced to a common average scale.

(c) Rectified prints - where tilt has been corrected.

(d) Enlargements - where the prints have all been enlarged by a fixed amount, e.g. x 2.

(e) Mosaics

(i) Index photographs laid out in strips showing their numbers for ease of reference to individual photographs;

(ii) Controlled - where photographs are laid out with care and using ground control and the overlaps are cut and the best fit made along the contact between prints. The whole lay down being re-photographed.

(iii) Semi-controlled - where photographs are laid down and cut with the best fit but little ground control is used except for showing a general North-South direction on the mosaic.

(f) Three dimensional prints.

Anaglyphs - complementary colours. Vectographs - Polarized and requiring viewers. Trivision prints where separate images are printed on corrugated emulsion. Three dimensional prints are not used in map making and are gimmicks used for display and in glossy magazines.

1.4 <u>Types of film, filter, season of photography</u>

(a) Panchromatic films are the films most frequently used because they are colour sensitive, fine grained for detail and the image they produce is "normal" to the human eye. (The pan films are sensitive particularly over the wavelengths 440 - 660 angstroms and the human eye is most sensitive around the greens 540 angstroms).

(b) Special purpose films -

(i) Infrared. Water absorbs all infra red and so water and swamp register black which is useful in soil mapping. Shadows also register black. Infra red penetrates haze. Species of trees vary considerably in their transparency to infra red, conifers showing black.

(ii) Colour films. Modern colour films are fine grained and fast and their resolution of detail is adequate for vegetation interpretation but they have been little used because they are expensive; they are usually processed by the manufacturer, and lighting conditions must be very good because they lack the tolerance of panchromatic film. Recently the Forest Service had an area near Tasman in Nelson province photographed in colour. These were excellent, giving marked contrasts within the forest and showing management differences on the nearby agricultural land. The use of colour prints is bound to increase.

(c) Filters. Yellow eliminates blue haze.

Green removes blue and red and thus intensifies contrasts in green and vegetation.

Red eliminates contrasts in vegetation.

The many combinations of film and filter possible enable special contrasts to be increased but unfortunately the cost involved in highlighting some special effect is very high and most photographs available have little contrast between vegetation types.

(d) Summer is usually the best season of the year for photography in New Zealand because the days are long with high sun and there is a considerable period when tonal differences are consistent. In countries where summer, autumn and winter landscapes differ considerably in colour and tonal contrasts advantage can be taken of the season of photography in photo interpretation.

1.5 Scale and focal length

The easiest way of expressing scale on air photographs is as the Representative Fraction (RF). The representative fraction is the natural scale ratio

$$RF = \frac{\text{Photo distance}}{\text{Ground distance}}$$

Frequently, however, scales are expressed as feet or chains to the inch or as inches to the mile and students would be wise to remember some of the common scale conversions because for most calculations the representative fraction is used.

Example RF = 1 : 15,840 = 1 inch to 1320 ft. = 1 inch to 20 ch. = 4 inches to 1 mile.

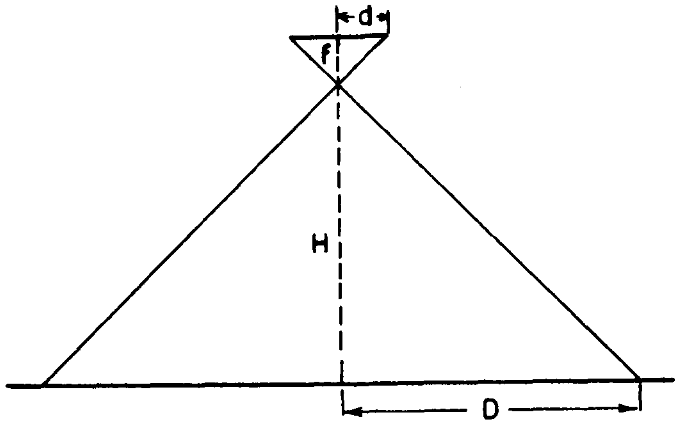


Figure 1.2

Figure 1.2 shows the relationship between the focal length of the camera (f) and the height above ground of the camera (H) which is the representative fraction, RF.

$$\frac{\text{Photo distance (d)}}{\text{Ground distance (D)}} = RF = \frac{f}{H}$$

As focal lengths are usually quoted in millimetres or in inches and flying heights in feet, care must be taken that the ratio $\frac{f}{H}$ uses the same measuring units for f and H.

For example, with a camera of 6 inch focal length, at 8000 feet

$$RF = \frac{f}{H} = \frac{f(ins)}{12H(ft)} = \frac{6}{12 \times 8000} = 1 : 16,000$$

Up to ten years ago much of the flying in New Zealand was done with 6", 8¼" and 12" focal length cameras with flying heights ranging up to 16,000 ft (above which pressurised aeroplanes are needed). Latterly, however, much work has been done with shorter focal length, wide angle lenses such as 3½" or 114.36 mm from 25,000 ft (a.s.l.) High definition is achieved by using fine grained film.

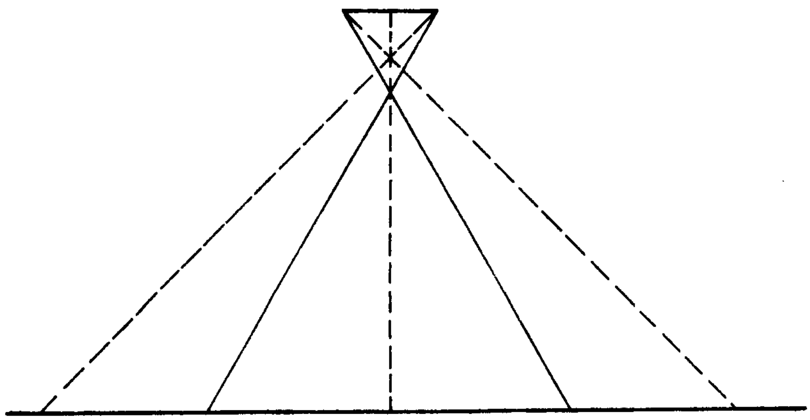


Figure 1.3

Figure 1.3 illustrates the effect of focal length on scale and area covered. Great savings in cost can be made by flying higher and using short focal lengths and thus achieving wider coverage. However, detailed examination of air photos on such a small scale requires magnification.

1.50 Selection of Scale

The selection of scale is usually determined by cost. Where special flights are made to photograph limited areas then the cost of additional prints needed to accommodate a larger scale will be small in proportion to the cost of the contract and so the best technical scale is chosen. However, when ordering photographs for land use surveys it is usual to choose the smallest scale on which the boundaries between the land categories can be recognised.

The following notes on scales are a guide when using normal hand stereoscope and field equipment:

1 : 31,680	2" to 1 mile	- Too small for the interpretation of vegetation except forest from non-forest.
1 : 24,000	1" to 30 chains	- Broad classification of forest stands. Major differences in grasslands, e.g. tussock from scrub from ploughed.
1 : 15,840	4" to 1 mile	- Useful scale particularly for indigenous forest (shape of tree crowns) (9" x 7" old series)

1 : 12,000		About ideal for forest work, needs magnification for detailed work on crops and grassland.
Larger scales -	costs and amount of handling rise sharply after 1 : 12,000	
1 : 8000	1" to 10 chains -	This scale is favoured by landscapers though even larger scales are needed for detailed planning in this field.

1.6 Flying and Overlap

Flight plans can be prepared to give the most efficient coverage of an area but usually it is best to work to a regular pattern so that sorting, indexing and using the air photos is straightforward. Much of New Zealand has been flown in an E - W direction so that prints are oriented N - S. This makes life much simpler both in the field and in the drawing office.

To obtain the necessary coverage for stereoscopic examination 60% endlap is required along the flight lines, i.e. each photograph should overlap its neighbour by 60%. To tie the flights together it is necessary to have at least 15% side-lap and normally 30% is what is asked for. This is shown in Figure 1.41.

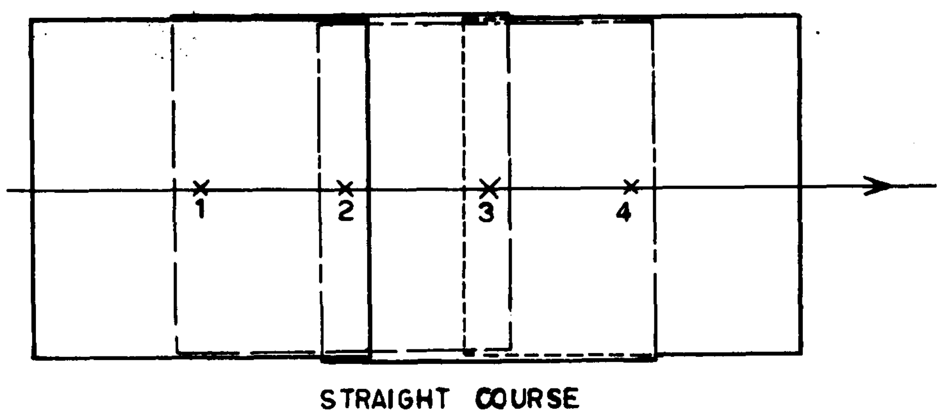
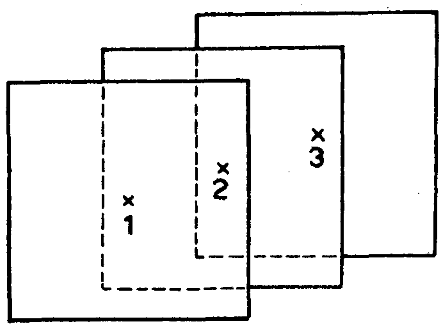
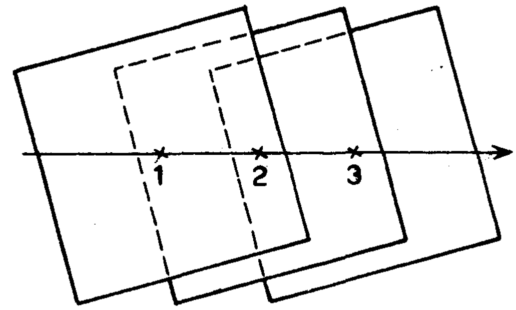


Figure 1.41



1.42



1.43

Figure 1.4

Figures 1.42 and 1.43 show the common errors found in flying.

1.7 Contract specifications

Each contract will be different in some detail from every other but the following points should be noted:

Item	Example
Scale	- 1 : 12,000 mean scale
Size of photographs	- 7" x 7"
Overlap	- 60% end lap, 30% side lap
Crab	- less than 10% of photograph affected
Tilt	- less than 4 degrees
Photographic paper	- semi matte bromide double weight
Film and Filter	- panchromatic with green filter
Date	- early summer - November or December
Time	- between 10 am and 3 pm
Degree of contrast	- defined by choice of paper and film
Photograph panel	- to show: flight number, serial number, focal length, altitude, date, time of day
Fiducial marks	- to be shown in each corner of print
Rebate	- on all four edges of prints
Number of sets	- three with flight diagram or two with index mosaic.

1.8 Availability of air photos in New Zealand

The Crown has a copyright on the air photographs taken by the N.Z. Aerial Mapping Company of Hastings who have photographed most of New Zealand for the Crown. The standard of air photo produced under this arrangement has been consistently high. However, it is surprising how much of New Zealand has been barely covered by photography and how little has been covered more than once. Perhaps the reason is the paucity of good flying weather.

Crown copyright prints are ordered through the Lands and Survey Department. The district offices hold the flight diagrams. The cost is $1.80 for the first copy of each 9 x 7 or 7 x 7 print and 43 cents for each additional copy - reduced rates for Government and local body purchasers.

The scales of most of these photographs range from -

1 : 15,840 taken on 8¼" lens for the old series (9" x 7" prints)

1 : 40,000 taken on 4½" lens for the new series (7" x 7" prints)

Enlargements up to 40" x 40" at about $13 each can be obtained and under certain conditions these photographs can be used to prepare mosiacs - usually ordered from the N.Z. Aerial Mapping Company through the Lands and Survey Department.

Much more photography has been done than that described above but it has been done for specific purposes and jobs.

1.9 Storage and indexing air photos

Air photos are bought to be used and archives of negatives and photographs are presumably kept by Government Land Offices and others. To encourage use it is necessary for the storage to be accessible, to give protection from atmospheric extremes, to keep the photographs flat and free from curling and to be indexed in such a way that they are easily found.

Experience indicates it is better to store the photographs serially by flight numbers rather than to try and devise some fancy arrangement according to geographical location.

Where the number of photographs to be stored is nearer a hundred than a thousand then the cardboard boxes in which they are delivered are adequate containers provided they are labelled well on the outside of the boxes and kept on shelves away from the heating system. Where large numbers must be stored then it is best to use a filing cabinet in which the photographs stand vertically.

CHAPTER TWO
MAPS FROM AERIAL PHOTOGRAPHS

2.0 Displacement on single air photos

An air photograph is not a map because images shown on photographs are not in their true positions relative to one another. This displacement may be due to the photographic equipment, or to tilt of the camera or to the topography of the ground.

2.01 Displacements due to the photographic equipment are technical problems of camera and printing. Such matters as the film being flat at the time of exposure, imperfections of the lens, dimensional stability of the films and paper, are very important when accuracy of a high order is required but are not very significant to field officers.

2.02 Displacement due to tilt is hard to detect. Objects on the down-side of a tilted photograph will be displaced toward the centre of the photograph and on the up-side away from the centre. Displacement due to tilt on photography that comes within contract limits of less than 4 degrees tilt is very small, for example displacement due to 2 degree tilt using an $8\frac{1}{4}$" focal length lens will be approximately 0.1 inches on the edge of the photo, 0.03 inches halfway toward the centre and nil at the centre.

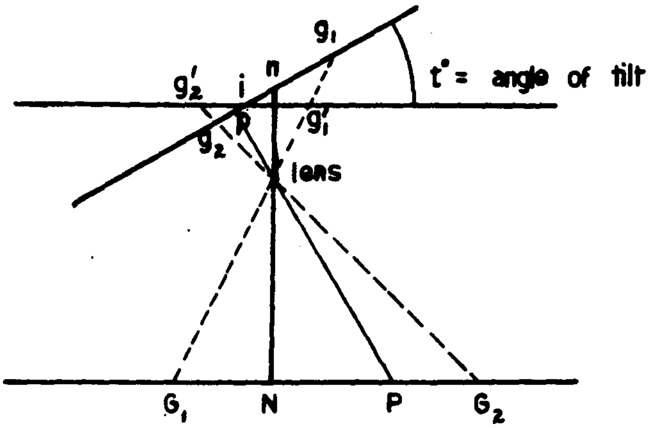


Figure 2.1

Figure 2.1 shows a tilted photograph. G_1 registers on the film at g_1 which is further away from the centre point p than $g^1{}_1$ (the point it would register if the photo was vertical). Similarly, G_2

registers at g_2 which is nearer the centre point p than g_2^1. However, where the angle of tilt (t) is less than 5 degrees the distance g_1 to g_2 is very nearly equal to g_1^1 to g_2^1 and measurements made will have very small errors, insignificant compared with measurements made with field equipment.

2.03 Topographic displacement

The following diagram illustrates the displacement on the air photo due to relief of the terrain. It should be noted that photograph will have less displacement near its centre than at the edges hence the centre of a photograph more accurately represents a map than the edges.

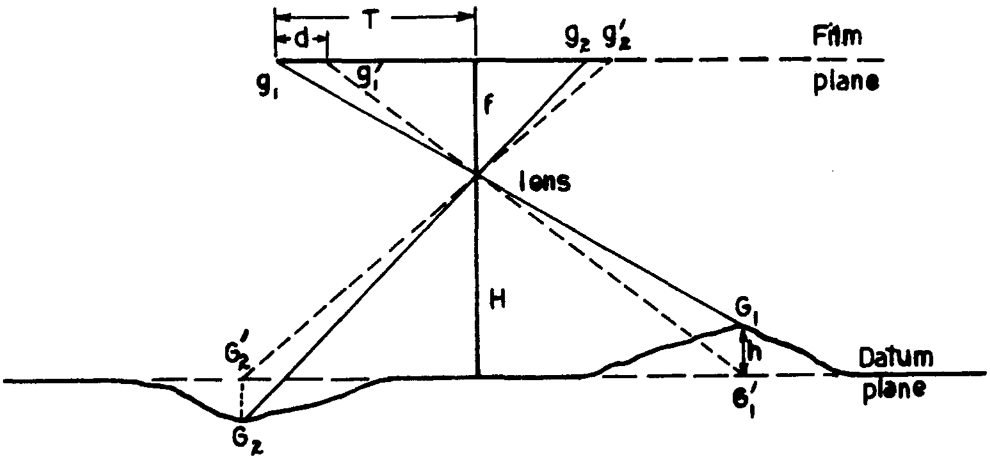


Figure 2.2

On Figure 2.2 g_1^1 represents the true map position of G_1^1 and g_1 the position its image shows on the photograph.

r = the distance of the image from the centre of the photograph
d = the distance the image is displaced
h = the height of the object (G_1) above the mean height of the topography
H = the height of the camera above the mean height of the topography.

and $\frac{d}{r} = \frac{h}{H}$

For example, where h = 1000' H = 8000 ' r = 5"

d (the displacement) = 5/8"

2.04 The effect of focal length on displacement

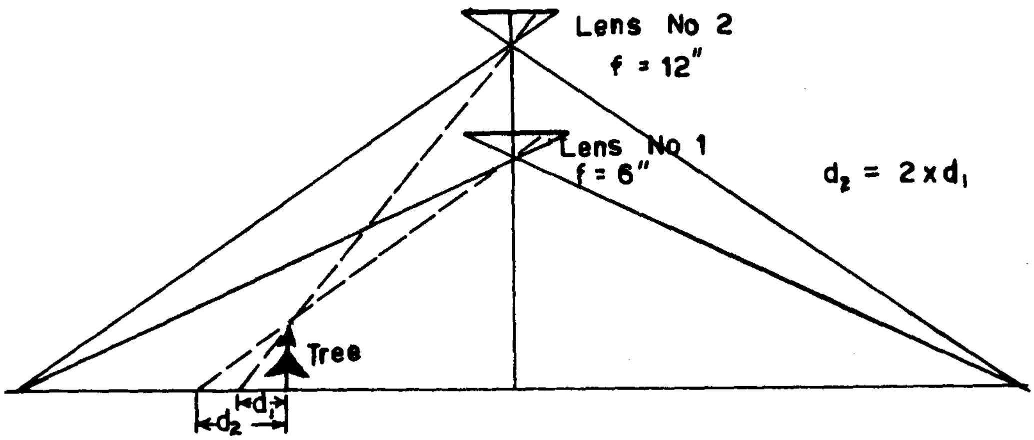


Figure 2.3

Figure 2.3 illustrates the fact that the focal length of the camera lens has considerable effect on the amount of displacement. As shown, the displacement due to the height of the tree is twice as great for the 6 inch lens as for the 12 inch even though the scale of the two photographs is the same.

2.05 Determination of height from topographic displacement on single air photos.

The best way to determine heights on air photos is to use stereoscopic pairs and equipment (see Chapter III) but occasionally it must be done on single photographs. Unless the scale is large it is unlikely that measurement will be accurate enough to give a valid answer. Suppose the Hilgendorf building at Lincoln appeared on a single vertical air photo, and that the wide angle lens had a focal length of $4\frac{1}{2}$ inches.

(1) Find the R.F. of the air photo

$$RF = \frac{\text{d photo}}{\text{d ground}} = \frac{\text{length of building on photo}}{\text{length of building from ground plan}}$$

$$= \frac{2.28''}{408 \text{ feet}}$$

$$= \frac{1}{2100}$$

(2) Find the flying height of the camera

$$RF = \frac{\text{focal length}}{\text{height of camera}} = \frac{f}{H} \qquad H = \frac{2100 \times 4\frac{1}{2}}{12} \text{ ft}$$

$$H = 792 \text{ ft.}$$

(3) Find the displacement on the photo due to the height of the building.

(i) distance from photocentre to top corner of building

r_1 = 111.4 mm.

(ii) distance from photocentre to bottom of the same corner of building.

r_2 = 103.8 mm.

(iii) displacement = $d = r_1 - r_2$ = 7.6 mm.

(4) Calculate height of building at that corner = h (Refer paragraph and diagram at 2.03).

$$\frac{d}{r_1} = \frac{h}{H}$$

$$h = \frac{d\ H}{r_1} = \frac{7.6 \times 792}{111.4} = 54 \text{ feet}$$

(Actually the height to the corner is 55 feet but measurements to 0.1 mm. accuracy are difficult to make).

2.1 The centre of the photograph

There are several points which can be considered the centre of the photograph and the reader should be aware of these as they are all mentioned in the literature.

(1) Principal point (designated P on the ground and p on the photograph). The principal point is the optical centre of the photograph, and is found by establishing the point where the lines joining opposite pairs of fiducial marks intersect. The fiducial marks are etched on the lens of the camera and appear on every photograph (in some English cameras p is etched on the centre of the lens). Distortion due to camera and lens is radial from P.

(2) Nadir or plumb joint (designated N on the ground and n on the photo). The nadir is the point which is vertically below the

camera at the time of exposure of the film. It is not easily located but tan a = d/f where a is the angle of tilt, d is the distance from p and f the focal length of the lens (both the direction and angle of tilt need to be known to find the nadir).

Distortion due to topography is radial from the nadir.

(3) Isocentre (designated I on the ground and i on the photo) The isocentre is the point of intersection of the plane of photography with the plane of the photograph had it been horizontal, and the line between n and p.

Distortion due to tilt is radial from i.

Refer to Figure 2.1 which shows all these points.

2.11 Assumptions

In truly vertical air photos p, n and i coincide. Because the tangents of small angles are very small then the distance between n and p must be small (i lies between them) when a, the angle of tilt, is small. For example, if a = 5 degrees and f = 114 mm. the distance n - p is less than 1 mm. When a contract calls for less than 4 degrees tilt and the contract is fulfilled the assumption that p, n and i coincide is valid.

This is known as the Radial Line Assumption and is a basic assumption of the mapping methods usually used.

2.2 Line of flight

When photographs are taken with more than 50% overlap (contracts usually specify at least 60%) the position of the centre point of the first photograph can be found on the second and vice versa. The line joining the two points represents the line of flight. The principal points transferred from one photograph to the next are usually referred to as the conjugate principal points.

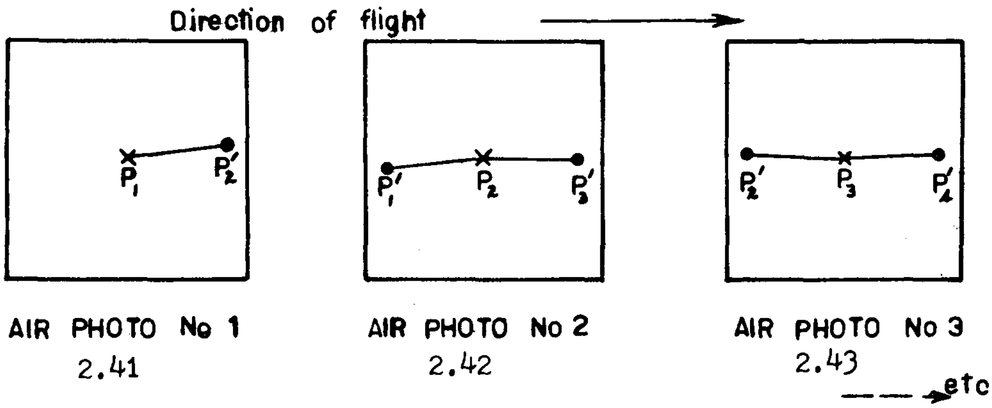


Figure 2.4

In the diagram the lines $P_1 - P_2{}^1$ (2.41) and $P_1{}^1 - P_2$ (2.42) represent the line of flight of the aeroplane between the two consequent exposures above P_1 and P_2. On each photograph within the strip the lines of flight from the previous photo and to the next will occur and can be drawn in. It should be noted that because of imperfections of navigation the lines $P_1{}^1 - P_2 - P_3{}^1$; $P_2{}^1 - P_3 - P_4{}^1$ etc. are not necessarily straight. The line $P_1{}^1 - P_2$ is drawn straight and the line $P_2 - P_3{}^1$ is drawn straight and the angle between them at the point P_2 represents the adjustments the navigator has made to keep the aeroplane and camera on the desired course and in the desired orientation.

2.20 Base line of the photographs

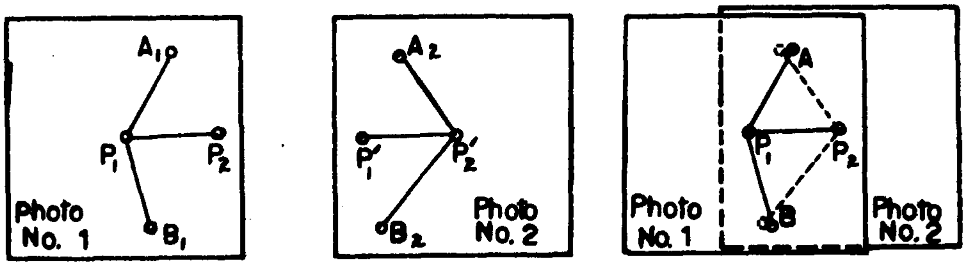
The line of flight, projected from the centre point to the edge of the photographs, is drawn in and becomes the base line of the photographs. As will be seen in Chapter III all stereoscopic work is done with the lines of flight of the parts of the photographs being examined parallel to the base line. When mapping, the photographs are orientated using the base line. In fact the first operation in practically all photographic work is to Base Line the photographs so that they can be correctly orientated.

2.3 Radial Line Triangulation

Maps can be prepared from air photos by first preparing a radial line triangulation of control points and then filling in the detail. The basis of the method (sometimes called the Arundel Method) has already been discussed; in summary it is:

(1) all displacements on the photographs are radial from the principal point (see paragraphs 2.0, 2.1)

(2) the flight lines of adjacent photographs coincide (2.2)



2.51 2.52 2.53

Figure 2.5

Two adjacent photographs of a strip, (2.51 and 2.52) are shown in Figure 2.5. The two principal points P_1 and P_2 have been marked and their conjugate positions P_2^1 and P_1^1 have been found. The flight line $P_1 - P_2^1$ and $P_1^1 - P_2$ have been drawn. Two wing points A_1 and B_1 have been found on photo 1 (2.51) and the same two points of topography have been marked on photo 2 (2.52) at A_2 and B_2. Radial lines to the wing points have been drawn to their respective principal points. The figure (2.53) on the right of the diagram shows how the photos overlap one on the other. The flight lines coincide and the true map positions of A and B are where the radial lines intersect.

A third photograph can now be added with the flight line $P_2 - P_3^1$ and $P_3 - P_2^1$ coinciding and with additional wing points C, D, E etc. radially established. In this way a strip of photographs can be tied together and a plot made showing the true map positions of the principal points and wing points. The wing points become minor control points (M.C.P's) of the plot. In practice at least six M.C.P's are required on each photo and, if they are near the upper and lower edges of the photo they can be used to tie in adjacent strips of photographs. If they are chosen above and below each principal point they will occur on three consecutive photos and can be rayed in to the principal points. In this case if the three rays form a triangle of error, instead of intersecting at a point, some error in plotting or transferring points has occurred and correction can be made.

Referring again to the diagram it should be noted that A lies somewhere along the line $P_1 - A_1$ and the angle $A_1 P_1 P_2^1$ is correct.

Similarly, A lies somewhere along $P_2 - A_2$ and the angle $A_2 P_2 P_1^1$ is correct. The correct position for A will be where $P_1 A_1$ and $P_2 A_2$ intersect which will be fixed by the length of the flight line $P_1 P_2$. It is evident that when fixing the length of the flight line between the first two principal points $P_1 P_2$ the scale of the plot is also fixed. This scale need not necessarily be the photo scale at that point but plotting is less complicated if it is nearly so.

2.4 Map projection - Orthographic

For large areas various other map projections are necessary but for the relatively small map areas field officers may want an orthographic projection is used - i.e. the assumption being that the earth is flat and a plane tangential to the earth's circumference where the map is made.

2.5 Ground control

If there are trig points already tied into the national maps within the area being plotted by radial line plot they should be discovered and marked on the photos to be used as control points in the plot. In this way the plot can be tied into the maps and given its correct orientation and its correct scale can be found. Preferably this ground control should be found over the whole plot or around its circumference. A ground control point in each corner is better than twenty down one side. It is possible to obtain plots of the centre points of photographs they have used in preparing maps from the Lands Department. If this is done much draughting time can be saved (and accuracy obtained) by using these plots and transferring on to them only the additional field data marked on the photographs and superimposing this material on to the topographic maps prepared by skilful draughtsmen.

2.6 Templates

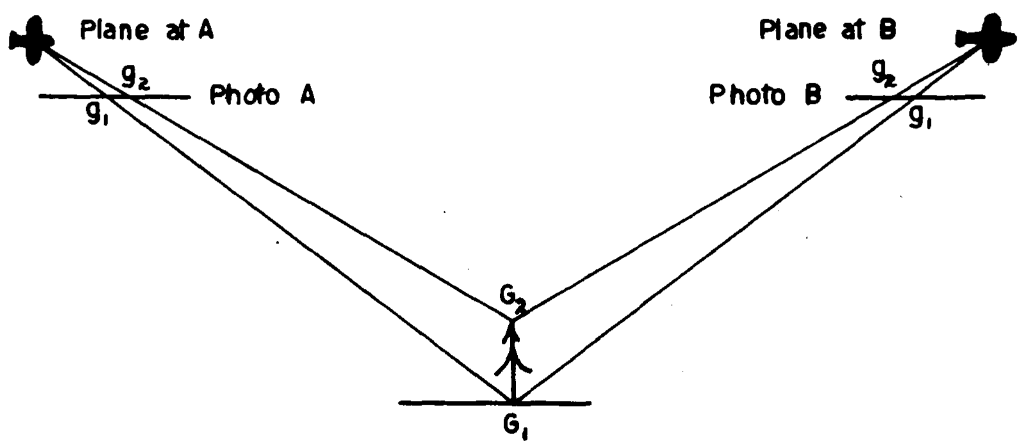
The graphical method of obtaining a radial line plot outlined above is very laborious and where much of this work is done it is usually accomplished using slotted templates. A slotted template is a slightly stiff plastic overlay for each photo on which the flight lines and rays to the control points are punched out to form slots. The templates are then assembled with pins through the slots so that the pins slide to the correct intersecting positions. When the templates have found their correct positions the pins are pricked through to mark their positions on a base plan.

CHAPTER THREE
STEREOSCOPY

3.0 Three dimensional images

When air photos are taken with a 60% overlap the objects on the ground are recorded from two view points. The distance between the view points being the distance between the air stations of the aircraft at the time the exposures were made. If the photos are then viewed with one eye seeing the first photograph and the other the second, the observer is able to see the objects on the ground from both view points at the same time and the image he creates in his mind's eye has three dimensions. The image so created has three dimensions because of the distance apart of the air stations, this is many times greater than the distance between the eyes so, in fact, the effects of height and depth are magnified relative to normal sight and to horizontal distances.

Figure 3.1 illustrates how a three dimensional image of a tree can be re-created. Two photographs of a tree from successive air stations A and B appear in Figure 3.11. In Figure 3.12 these are located in the same relative position as they were when taken and viewed one with each eye.



3.11

Figure 3.1

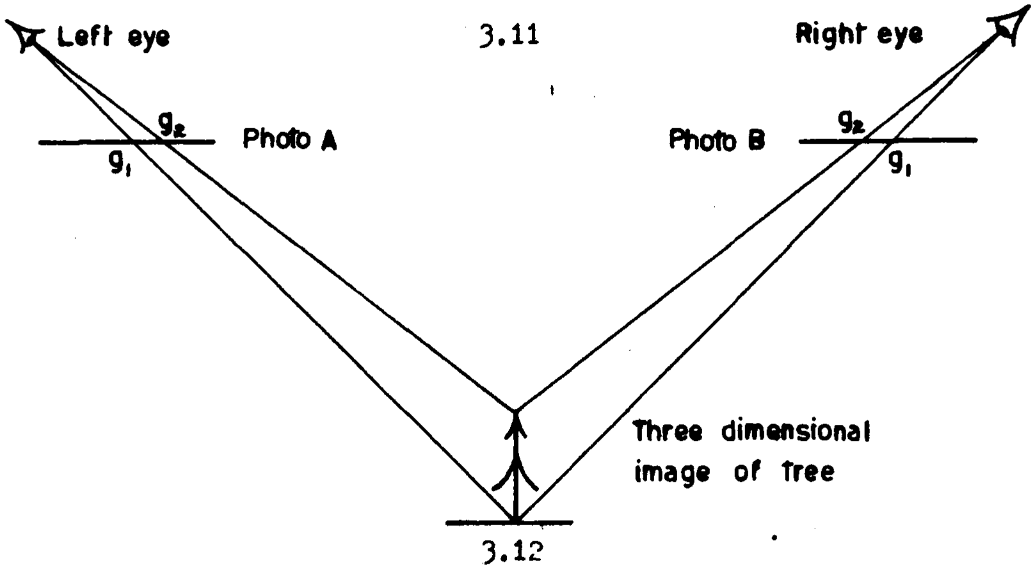


Figure 3.1

Much can be learned by studying the two dimensional images on single air photos. We are used to seeing objects at a distance where the stereo and range finder effects of our eyes are so slight that our estimates of distance and interpretation of what we see depends on a sub-conscious interpretation of shadows, shape, tone, relative size and arrangement. Studying single air photos is like seeing at a distance or viewing with one eye, the image has only two dimensions and any three dimensional effects are super-imposed on the image by our brains. The subjective image of three dimensions created when looking at single air photos is no substitute for the image viewed when examining stereo-pairs. The latter can be measured.

3.1 Types of stereoscope - Prism, Lens, Mirror.

A stereoscope is an instrument used as an aid to viewing stereo-pairs of photographs. Actually, it is possible to look at stereo-pairs without the aid of an instrument simply by looking at the left hand photograph with the left eye and the right hand photograph with the right eye, but few untrained observers can do this as it requires the independent operation and focusing of the eyes. The stereoscope has an optical system which makes viewing easier and at the same time magnification and conveniences such as the wider separation of the photographs can be introduced.

3.10 Prism Stereoscopes

The simple stereoscopes, used with the parlor toys popular forty years ago, are simple prisms which deflect the line of sight to give an image from both the left hand and right hand photographs. This is shown in Figure 3.2

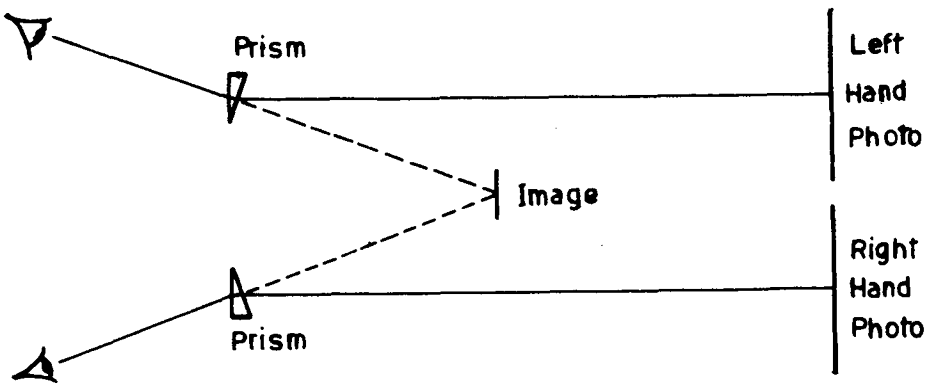


Figure 3.2

3.11 Lens Stereoscopes

The hand stereoscope made with simple lens is cheap, portable and easily positioned. It gives some magnification and is quite the most useful instrument for field use and field interpretation of air photos. Normal convergence of the eyes is overcome because in effect the lenses increase the focal length of the eyes. (See illustration in Section 5.0)

3.12 Mirror Stereoscopes

Mirror stereoscopes have the advantage that the photographs are mounted separate from one another and remain in their same positions whatever part of the stereo pair is being examined. The instrument is moved about over the mounted pair (with its axis parallel to the base lines of the photos) and there is easy access to the photographs for marking and measurement. The mirror stereoscope is the primary instrument for all interpretation and measuring work done by field officers. Various attachments and measuring devices can be added making a wide range of equipment available.

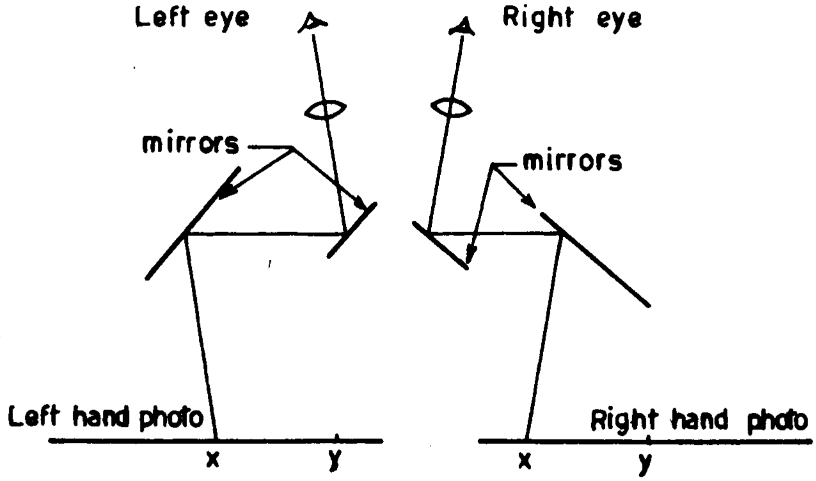


Figure 3.3

Figure 3.3 illustrates the basic optical system of the mirror stereoscope.

3.13 Pseudoscopic images

Occasionally observers are troubled by what is called a psdudoscopic image where the relief is inverted and valleys appear as hills and hills valleys. The origin of this effect is usually -

(a) interchange of the left and right hand photos under the stereoscope - correction by swapping the photos.

(b) improper lighting either when viewing single air photos or very occasionally stereo pairs - correction can sometimes be achieved simply by blinking or winking but better light and changing the orientation of the photos so the shadows fall toward the observer may be required.

3.2 Parallax

3.20 Parallax is the displacement of one object with regard to another. The reason air photos cannot be treated as maps was shown in Chapter II to be due to the displacements on the photos. This same displacement enables height to be observed and measured. Apparent height when viewing a stereo pair is due to the combined displacements on the two photographs.

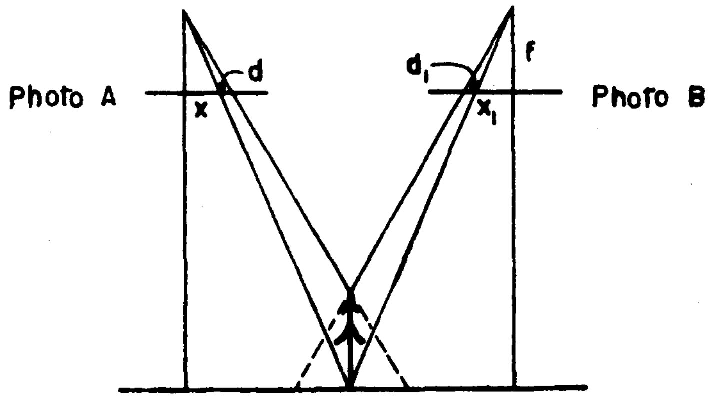
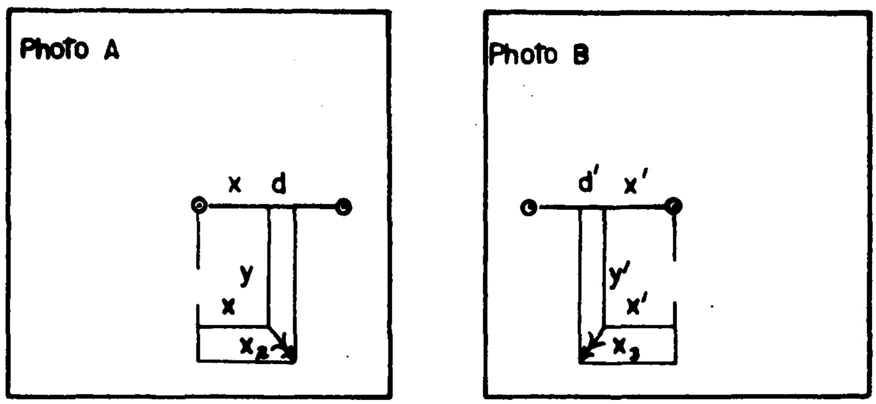


Figure 3.4

Figure 3.4 shows the relative positions of the object and the camera when successive photographs are taken.



3.51 3.52

Figure 3.5

The image as it appears on the photographs is shown in Figures 3.51 and 3.52.

In Figures 3.51 and 3.52 the absolute parallax of the bottom of the tree = $x + x^1$ and the absolute parallax of the top of the tree = $x_2 + x_3$. The difference of absolute parallax of the top and bottom of the tree = $(x_2 + x_3) - (x + x_1) = d + d^1$.

The parallax difference ($d + d^1$) is proportional to the height of the tree.

3.21 The absolute parallax $(x + x_1)$ or $(x_2 + x_3)$ will be the same for all points at the same elevation all over the overlap provided there is no tilt and provided the two principle points are the same elevation. If the two principle points are the same elevation then the distance between them (the mean of the distance measured on each photograph) is the absolute parallax.

3.22 Y Parallax

In the diagram the y parallax would be the difference between y and y^1 (for the base of the tree). If there is no tilt and the flying height is the same for both photographs y parallax is zero. Large y parallax would hamper stereoscopic study and for our purposes we will not discuss it further.

3.23 Note of warning

Parallax is also the term used when photographic images are optically superimposed for transferring detail and the movement of the observers eye moves the images relative to one another - because the optical distances are different. In this case the parallax refers to the instrument rather than the photograph. You may have experienced parallax in microscopic work, again this is within the equipment rather than in the object viewed.

3.3 Parallax Formulae (For derivation of formulae see the standard texts and A.H. Simpson, pages 8 - 10).

In Figures 3.51 and 3.52 absolute parallax $= x + x^1 = P$

Parallax difference of tree image $= d + d^1 = d^P$

$$\frac{h}{H} = \frac{d^P}{P + d^P} \quad \text{or } h = \frac{H \times d^P}{P + d^P} = \frac{H.d^P}{b_{m.}}$$

$$RF = \frac{f}{H} \quad \text{or} \quad h = \frac{f \times d^P}{R.F.\ (P + d^P)}$$

where h = height of image

H = Flying height

RF = Representative Fraction

f = focal length of camera

h and H are usually measured in feet

dP and P are usually measured in either millmeteres or inches (but not both)

Because dP is relatively very small $(P + d^P)$ is approximately equal to b_m

b_m = the mean horizontal air base distance measured on the photographs.

<u>Note</u>: (i) d^P is proportional to the absolute parallax and inversely proportional to the flying height. Thus at a given scale the difference will be greater for a short focal length camera (taken at a lower height) than for a longer one and a 9" x 9" photograph will show more than a 9" x 7" (where both photographs have a 60% overlap) because the flying base is larger on the 9" x 9".

(ii) The assumption, that the base length b_m = P the absolute parallax, can cause difficulties when spot heights are being taken. This is shown in Figure 3.6. In topographic mapping heights are all referred to the datum plane of the principle points, but when taking spot heights of the top and the bottom of a tree the absolute parallax may not equal b_m.

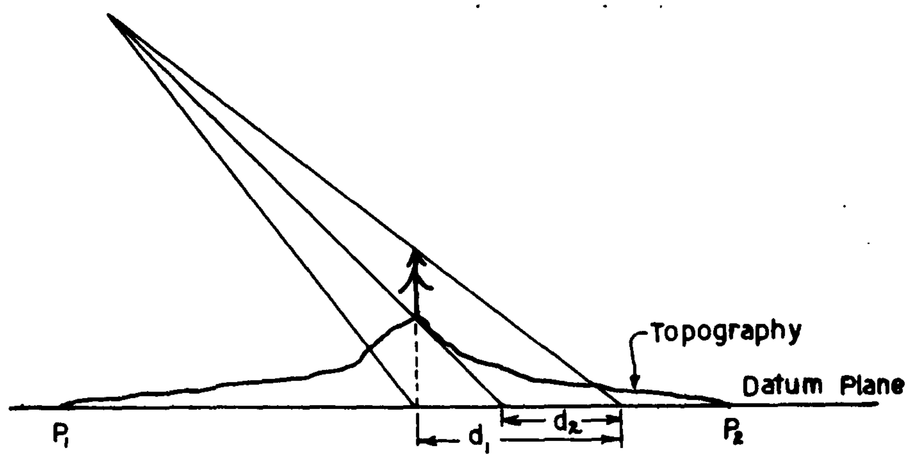


Figure 3.6

In the diagram if we assume $P = b_m$, $d^P = d^1$ but we want $d^P = d^2$. There are standard procedures for correction for absolute parallax (P) when it differs from base length (b_m).

3.4 <u>Measurement of parallax</u>.

3.40 Direct measurement of parallax on each photograph separately as illustrated in Figures 3.51 or 3.52 may be theoretically possible, but the distance d^P is so minute it is impractical.

3.41 The parallax bar (or stereometer) consists of two transparent overlays each with a mark etched on them. The marks are overlaid on the image of each photograph under a mirror stereoscope so that they fuse and appear as one. If they are separated slightly the fused image will appear to descend and if they are brought together it will appear to ascend. If the movement is too great the marks will separate.

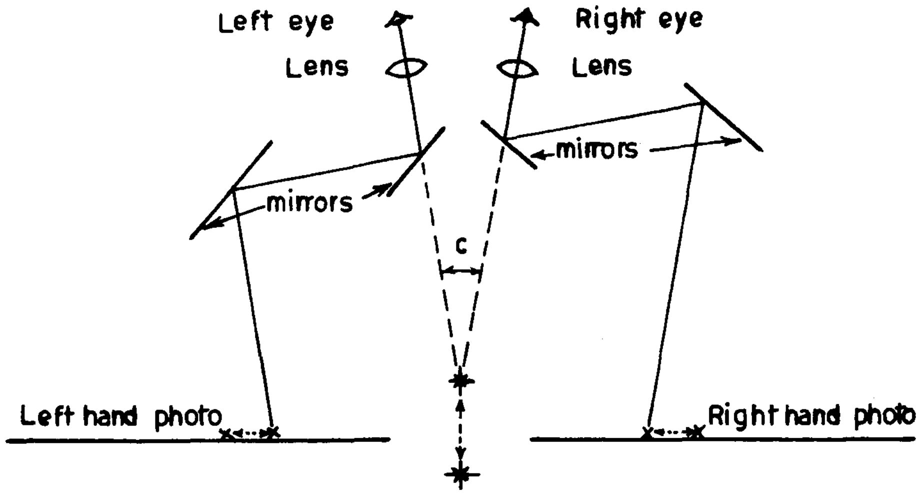


Figure 3.7

With reference to Figure 3.7, by shifting the marks x the angle c is altering slightly and the imaginary image (*) will move up and down. The sensitivity of the observers eyes to minute changes in the angle of convergence (c) is the controlling factor in his ability to measure parallax.

Average observers can detect parallax differences of 0.002" and skilled observers 0.001".

CHAPTER FOUR
PHOTO-INTERPRETATION

4.0 Bird's-eye view

Aerial photographs have two distinct advantages over observations made from the ground:

(a) The point of observation is high above the earth and there is an unobstructed view in all directions.

(b) The third dimension of the images is exaggerated several times.

The advantage of (a) is obvious, but in addition to the unobstructed view, patterns of land form, vegetation and development are more readily observed on the photograph than from the ground.

The exaggeration of the third dimension, in the mind's eye, enables even slight differences in relief to be observed. Three-dimensional perception is lost at greater distances than half a mile when observing from a single point, as on the ground, but with a stereopair of aerial photographs the whole of the observation area can be seen stereoscopically.

4.1 Recognition and Identification : "Photo-reading"

The aim of photo reading is to make an unquestioned identification of what is seen. The ability to do so depends on the interpreter's familiarity with what he is trying to observe. The value of air photos lies not in the total absence of field work but in a reduction of the amount.

A geologist will interpret geological formations on the photographs which are unintelligible to a layman. Similarly foresters of forest, agriculturalists of agriculture, land administrators of land management, town planners of urban use and landscape architects of landscape. In fact "beauty lies in the eye of the beholder". In a technical sense "beauty", the detail of what is interpreted, depends on the technical interpretation of the observer. Photographs are no substitute for technical skill. However, photographs are an aid which accelerates the teaching of these skills and they are an indispensable adjunct to the training of anyone technically involved in land use.

4.2 Comparison

Most land use research work is achieved by comparison, analogy and correlation. These methods are also the basis of all photo interpretation procedures. Field workers of the old school will criticise photo interpretation of land use as "canned geology", "canned forestry", "canned this or that" but every chef knows that canned goods can be made to enhance a fresh food diet particularly where some of the fresh ingredients cannot be gathered:

The basis of the comparisons and analysis made in photo-interpretation is experience. The more work that is done with photographs in the field the quicker, easier and more certain office interpretation will become. Work with the photographs in the field makes unquestioned identification possible. A corrollary is that field work is also quicker and easier because with good interpretation field work will be restricted to:

(a) The collection of data which can only be measured on the ground, e.g. plot measurement of forest samples, examination of soil profiles.

(b) The interpretation of those features on the photographs where "unquestioned" identification is not possible either because of smallness, obscurity or inexperience.

(c) The recognition in land use survey work of area boundaries on the ground so that extrapolation of the boundary lines can be made on the photographs.

4.3 Keys or stereograms

A valuable aid to experience is a set of examples known as keys or stereograms. A stereogram is a selected part of a stereopair, mounted on a card as a permanent example for reference. Each stereogram will show a particular feature.

Foresters have developed the art of representative stereograms to a very high order. They have examples of pairs showing stocking rates, crown density, age classes, forest types native and exotic and so on. These are at various scales which can be used for comparison with newly flown photographs. Such comparative work can be used for estimates of growing stock and the like. There is an urgent need for similar examples to be prepared for agricultural work and if only as teaching examples for classes at this College.

4.4 Identification of detail on photographs

What characteristics of the photographic surface enable us to identify what we are looking for? In the process of viewing we record in our memory various items with which we became familiar and identification is based on our memory associations. There are few words and a poor vocabulary to aid recall and the situation is similar to our description of smells. Words like acrid, pungent, sweet etc., are only general descriptions and we recall our familiarity with smells by remembering for example onion-like, faecal, like daphne, orange-like, Chanel No 5.

In photo-interpretation the value of examples or stereograms mounted for reference is real but, as is usual, experience is based largely on unconscious reference to our memory based on repeated, frequent, regular and for preference recent observation. The more stereopairs examined the better the observer becomes. Some people are much better than others!

4.5 Size, shape, tone, texture

The four main features on which identification is based are size, shape, tone and texture. In addition there are two features we use, shadow and familiarity of pattern, which are based on the above and which are unconsciously used as part of experience.

(a) Size - The actual size of the image is dependent on the scale of the photographs and large scale photographs are more suitable for studying the particular. However, relative size is both consciously and unconsciously important for recognition.

(b) Shape - is perhaps the most important characteristic for identification of man-made objects and discrete individual things such as tree crowns (species recognition), houses or factories, hedges etc. Care must be taken to associate shape with size. Shape and patterns of shapes are important associations also. Viewing in third dimension under the stereoscope gives a 3D shape hence the importance of taking a stereoscope into the field and wherever possible using stereopairs instead of single photographs.

(c) Tone - is the term used to cover all the grades from white-grey-black. We have seen how colour will influence tone and the importance of the season of photography. Tone is the basis of all photography - there would be no photographs without it. Special photography such as infra-red to emphasize water and dampness is useful because the dark tones are emphasized by these features on this film. Panchromatic film is usually chosen because its tonal range is similar to the sensitivity of normal eyesight. Exposure, either under or over, influences tone but normal film can be printed so that the tonal range is even over the whole print and from one exposure to the next.

(d) Texture - is the evenness of tone or the variation of the micro-patterns of tone. There can be even texture, mottled texture etc. Texture is of critical importance in vegetation identification.

4.6 Resolution

Resolution is another property of photographs which is critical for interpretation. Resolution is the amount of detail visible in the photograph. It is a physical property of the photo dependent on the quality of camera and lens, processing of film and the grain of the film.

Associated with resolution is Image sharpness. How sharp an image is set off from the surrounding area. Even in good photography, where the tones of adjacent images are very close, their separation is difficult. One reason why photographs of urban areas are easy to handle is because they are contrasting in tone over much of their area and an observer can orientate them rapidly and with confidence whereas areas such as tussock plains without such easily-identified features take more practice.

4.7 Basic steps in Air Photo Interpretation

(1) Source material. Sort out the photographs available of the area to be examined; there may be coverage from several different sources. There may also be previous surveys and map data available - search for it, enquire.

(2) Calculate the scale of photography.

(3) Lay the photograph coverage out on a large table. Orientate them in roughly their correct position. Sketch an index showing flight numbers and the direction the serial numbers are running.

(4) Mark, with chinagraph or other easily erased crayon, the orientation features e.g. river names, ridges, terrace edges, etc (Mark only on alternate photographs, say the even serial numbers).

(5) Pre-field study. Spend as much time as you can afford making yourself familiar with the photographs, particularly the technical features of your interpretation e.g. if it is a forest survey you should be able to mark in most of the forest type boundaries before field work.

(6) Field study. This should be confined to areas of doubtful interpretation from the pre-field study and to the collection of essential field data. Always use a pocket stereoscope in the field and make interpretations on the spot. It is

surprising how much more vivid the memory of such field interpretation is compared with office work.

(7) Post-field study. It is most important that immediately after the field study all boundaries marked on the photographs should be checked and no gaps or ommissions remain. Further, clear and precise legends of all types, field notes and area descriptions, should be completed.

4.8 Measurement as an aid to photo interpretation

The following are measurements which can be made fairly readily in the office which can aid interpretation and save unnecessary field work.

(1) Scale - absolutely basic to interpretation

(2) Scale variation in individual photographs and over the flight

(3) Distances and distortion of distances

(4) Height with parallax bar or equivalent

- (i) spot heights of topographic features
- (ii) heights of individual structures - trees, etc.

(5) Slopes e.g. road grades, slope groups

(6) Areas, particularly areas within boundaries interpreted and defined on the airphotos. Area distortion.

(7) Density grids and other prepared material, printed on film negative, for comparison.

4.9 Further notes

(a) Work methodically - a high proportion of time spent on interpretation is spent handling the photographs, particularly on vegetation and land use surveys. Unless the interpreter is systematic in laying down and picking up flights and runs he will create a frustrating shambles and spend too much time sorting untidy piles of photographs.

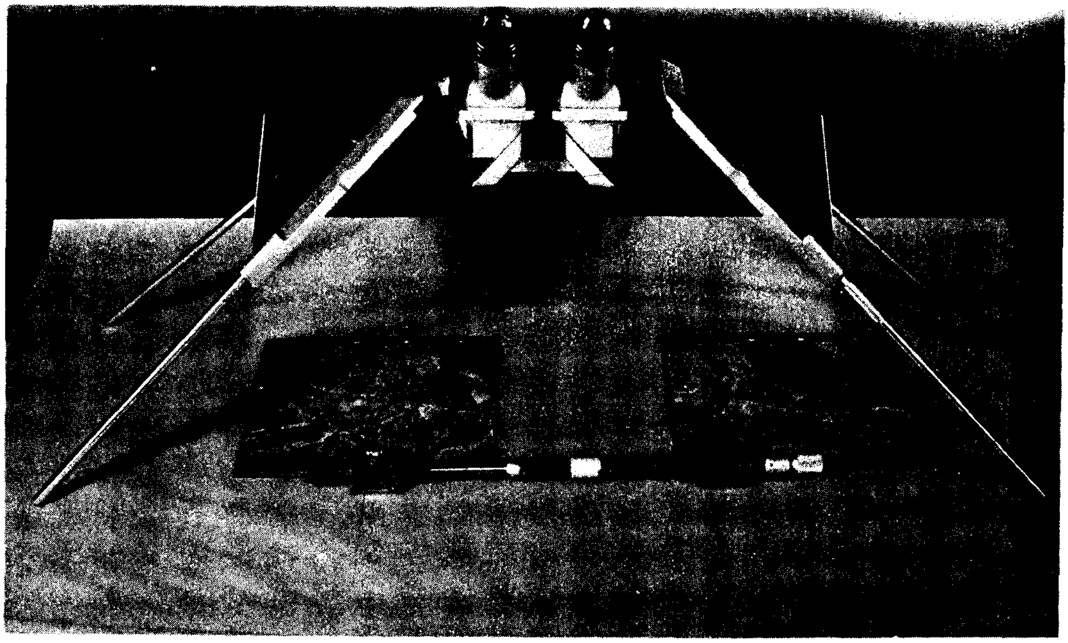
(b) Corroborate evidence. Try always to make interpretations two or more ways; it is easy to jump to conclusions - for instance, a structure in Canterbury may look like an irrigation race, on the other hand the same structure may be a stock water race, or a drainage ditch. Size, intake or origin, outfall, position, secondary structures, e.g. border dykes, will corroborate and an unquestioned interpretation should not be difficult.

(c) Pragmatic information. It is quite legitimate to use pragmatic knowledge to corroborate interpretation - for instance in the Rotorua district the even-textured tree crowns in native bush on the ridge tops are likely to be tawa trees, the dominant trees mid-slope are likely to be rimu or matai and on the flats near the streams are likely to be kahikatea. That is where these species grow.

THE POCKET STEREOSCOPE

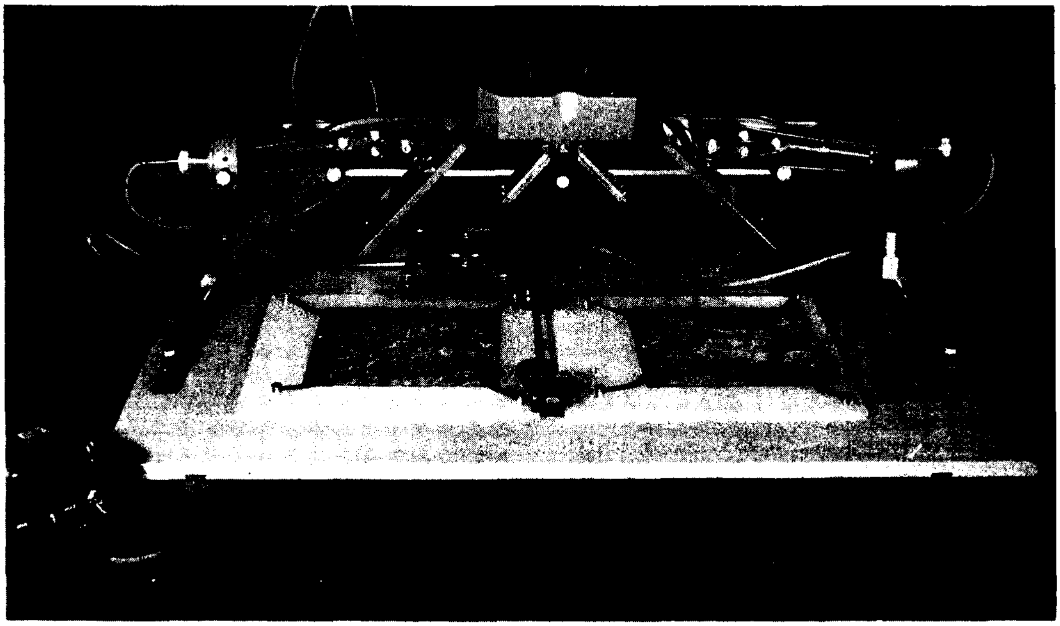
Hold the stereoscope and left hand photograph still, and move the right hand photograph into the field of vision from the right until the stereoscopic model (3D effect) becomes apparent. The line of flight on the photographs and the axis between the eye pieces of the stereoscope must be parallel. The eyes can accommodate considerable errors in position but they will become tired quickly unless the photographs are correctly orientated. Speed and accuracy of orientation come quickly with practice.

Plate 1



THE MIRROR STEREOSCOPE (WILD ST4)

The illustration shows the parallax bar (stereometer) in position. The photographs can be positioned by eye but usually it is better to draw up a paper underlay showing the line of flight and two perpendiculars (which pass through the centre points of the photographs) and to mount the photographs on it. Once the photographs are mounted the instrument can be moved for viewing and measuring the whole model, care being taken to keep the axis of the instrument parallel to the line of flight.

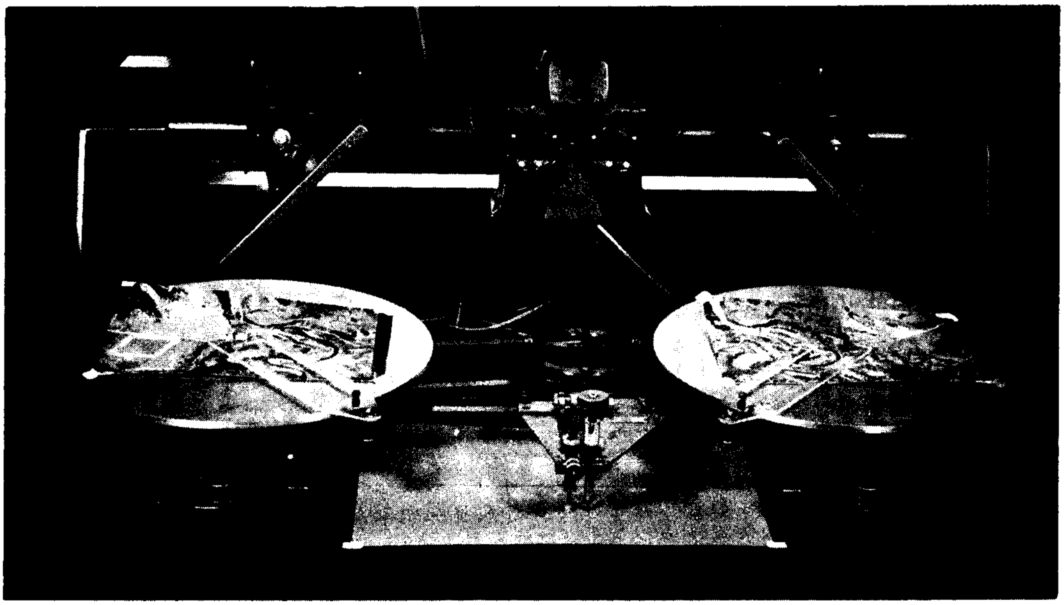


MIRROR STEREOSCOPE WITH ANCILLARY EQUIPMENT
(Hilger Watts SB 181-184)

As illustrated this stereoscope has:

(i) A parallel guidance mechanism so that the instrument stays still and the photographic model is moved underneath it, the axis always parallel to the line of flight.

(ii) A stereometer built into the optical system using a spot of light as the moving dot.



RADIAL LINE PLOTTER
(Hilger Watts SB 100)

This instrument is the simplest equipment available for stereoscopic transfer of data from aerial photographs to plans and maps. The photographs are mounted with a radial arm pivotting on the centre points. When viewed through the stereoscope the point where the radial lines intersect corresponds to the position of the pencil mounted over the map on the table as shown. The position of the centre points must first be established on the map.

Plate 4

PROBLEMS

7.0 The best way to learn to understand the simple geometry of aerial photographs is to play with problems. The following problems are examples which require no mathematical skill for solution. If you cannot get them out, refer to the text.

1. An aircraft equipped with a camera of $4\frac{1}{2}$ inch focal length lens flew over the suburb of Cashmere in Christchurch at 3,100 feet altitude above sea level (a.s.l.) What was the approximate length in inches measured on the photograph for:

   (a) a city block 220 yards long on the flat below the hills 100' a.s.l.?

   (b) the frontage of a section at 700' a.s.l. was 0.4 inches measured on the air photo. What is the length of the frontage in yards?

2. (a) Working on a single photograph of a city it was found that a building was 0.8 inches long (photographic distance) and the plans of the city showed it to be 160' long. If the camera had a focal length of 12 inches what is the representative fraction of the photograph at this point? and the flying height of the aircraft?

   (b) If the base of the building was 2.6 inches from the principal point of the photograph and the top was 2.95 inches, what is the height of the building?

3. Given the flying height of an aircraft as 8,000'
   the focal length of the camera as 6 inches
   the base length of the photograph's b_m as 73 mm
   the parallax bar reading at the foot of a tower 10.52 mm
   the parallax bar reading at the top of a tower 10.87 mm,

   What is the height of the tower?

4. An aircraft with a camera using a $3\frac{1}{2}$ inch focal length lense flying at 25,000' (a.s.l.) photographs a mountainous area. A known trig. at 4,800' had a parallax bar reading of 14.45 mm and a mountain hut at an unknown altitude had a reading of 10.95 mm. The distances between the principal points on two photographs were 75 and 71 mm.

What was the altitude of the hut?

5. (a) An aircraft operator flying over downland using a camera of $3\frac{1}{2}$ inch focal length was asked to take photographs on a mean scale of 1 inch to 20 chains. What height should he fly above the mean height of the area?

(b) Flying at the above height with the same concern he took photographs of a farm. It was decided when planning the development of the farm to pump water from a well to troughs. The pumps available would only allow a lift of 100' up a fairly steep hillside above the well to a storage tank. If you were to site the tank on the air photographs what would the parallax difference of the well and the tank be? The base length (b_m) of the photographs being 42 mm.

6. A stereoscopic pair of vertical aerial photographs of the College playing fields, showing the water tower, had been damaged but from ground measurements and from measurements on the photographs the following data were gathered:

The height of the tower is 80 feet
The scale of the photograph is 1 : 23,272
The distances between the principal point and the conjugate principal point of the two photographs are respectively 73 mm and 71 mm.
The parallax bar reading on the top of the tower is 10.87 mm
The parallax bar reading on the base of the tower is 10.51 mm.

(a) What was the flying altitude of the aircraft above the field?

(b) What is the focal length of the camera lens in inches?

7. An aircraft equipped with a camera $4\frac{1}{2}$ inch focal length lens, flew over Lincoln College at an altitude of 8,000'. The 9" x 9" photographs taken were vertical with 60 per cent overlap. The distance between the principal points on two consecutive photographs showing the south-west corner of the Hilgendorf Wing was 67 mm and 69 mm. It is known that the building is 54' tall.

(a) What is the scale of the photographs?

(b) What is the parallax difference between the roof and the ground floor of the building?

(c) If the south-west corner of the building at roof level is 4.63 inches from the centre point of one of the photographs and the centre point of the photograph coincides with the north-west corner of paddock S.30 on the ground, what is the distance, to the nearest chain, from the north-west corner of paddock S.30 to the south-west corner of the building.

7.1 Revision

You are required to order photographs of a small catchment (3,000 acres) for a development programme which you know will require stream realignment and tile drains in the lower catchment, and hill country development including an air strip on a flat ridge on one edge of the catchment. You know that the highest point in the catchment is 2,500' (a.s.l.), that the outfall of the stream is 480' (a.s.l.) and the proposed airstrip is 1,500' (a.s.l.). You know that the catchment is four miles long and at its widest point it is 2 miles wide (a mile on each side of the centre). You have decided that you want the photographs to be on a scale of 10 chains to one inch on the flats near the outfall and that the contractor who will do the flying has a camera with a lens of $8\frac{1}{4}$ inch focal length:

(a) At what height should he fly to photograph at the required scale?

(b) What will the scale of the photographs be at the airstrip and at the highest point?

(c) If he flies a strip down the centre of the main axis of the catchment with a minimum of 60 per cent end lap on 7" x 7" photographs what is the minimum number of photographs required to give stereoscopic cover of the whole length?

(d) With 20 per cent side-lap how many flight lines would be required to cover the catchment?

(e) The maximum ruling grade allowed on the access track to the airstrip is 1 in 5. What would be the parallax difference of two points on the road 10 chains apart where the road climbs along a siding near the airstrip without corners at the maximum grade? (Base length of the stereo pair covering this area is 58 mm).

(f) The base of an electric pylon on the flats near the outfall appears 2.6 inches from the centre point of a photograph and the top is 2.65 inches from the same centre point, how high is the pylon?

(g) A straight length of fence at an unknown altitude on a flat piece of ground is known to be 16 chains long. On the photograph the fence was measured to be 1.9 inches long, it was very close to the centre point. What was the altitude of the flat the fence was on? (Assume the flying height of the aircraft was constant throughout the photographing contract).

(h) When realigning the stream it is known that the maximum slope permitted on the new waterway was 1 in 60. The realignment must pass through a certain culvert which is at 519.6' (a.s.l.) and must pass through the existing outfall. The direct distance between these two fixed points is 30 chains, the slopes of the land are very even and the alignment will probably be made as an S-shaped curve between the culvert and outfall. What will be the parallax difference between points 9 chains apart along the curve - the base length of all pairs of photographs being 68 mm? Would there be any point in attempting to find these points with a parallax bar?

(i) At one point on the waterway you know you will want to instal a tile drain and reach as far back away from the waterway as you can. The slope of the land is 2^{o} very long and even and its aspect is at right angles to the waterway. You know that for technical reasons the maximum depth of your tile is 6' and the minimum at the point of entry tile is 1 foot. The minimum slope permitted on the tile is $27\frac{1}{2}$ inches per chain and the maximum length of tile permitted is 40 chains. What is the parallax difference of the present land surface between the top and the outlet of the tile (bm - 68 mm).

(j) Near the top of the catchment there is a stream with a waterfall, the parallax bar reading at the lip of the fall is 14.45 mm and at the plunge pool 12.95 mm and the distance between the principal points on this stereo pair are 71 and 69 mm. From the map you know the lip of the fall is 300' below the highest point of the catchment. What is the vertical distance from the lip to the plunge pool?

(k) On the same pair of photographs the highest point in the catchment is marked and the long even slope leading up to it has the centre point of one of the photographs in mid slope. The photographic length of the slope is 0.60 inches, the parallax bar readings for the highest point and the base of the slope are 15.62 and 12.01 respectively. Into what slope group will this area of the map be placed on a land inventory survey?

7.2 Answers to Problems

1. (a) 1 inch
   (b) 71 yards

2. (a) R.F. = 1 : 2,400
   H = 2,400 feet
   (b) h = 122 feet

3. h = 30 feet

4. 3,800 feet a.s.l.

5. (a) H = 4,600 feet
   (b) dP = 0.94 mm

6. (a) H = 16,000 feet
   (b) f = $8\frac{1}{4}$ inches

7. (a) R.F. = 1 : 21,333
   (b) dP = 0.45 mm
   (c) 124 chains

7.3 Answers to Revision Problems

(a) 5,980 feet a.s.l.

(b) 1 : 6440 1 inch to 8 chains
1 : 5,040 1 inch to 6.4 chains

(c) 17 photographs

(d) 5 flight lines one central run and two on either side.

(e) 1.70 mm

(f) 104 feet

(g) 1,370 feet a.s.l.

(h) 0.12 mm. No point in attempting to plot using parallax bar. Waterway would be 36 chains long and the length would dictate the shape of the S curve. Also 0.12 mm is too small to plot with any reliability.

(i) 1.14 mm

(j) 81 feet

(k) slightly less than 35°. Slope group F.

An Introductory Handbook for Students and Field Officers.

PHOTOGRAMMETRY FOR AGRICULTURE