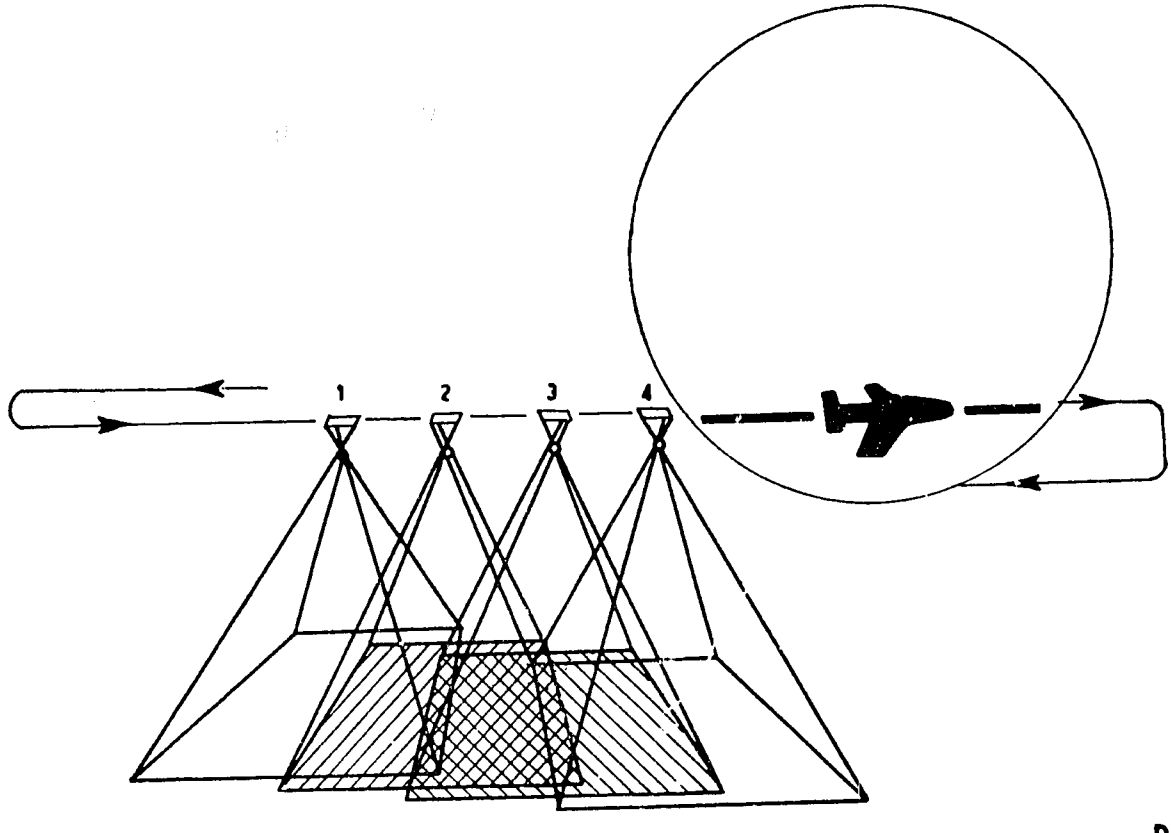
FUNDAMENTALS OF PHOTOINTERPRETATION AND PHOTOGRAMMETRY



By
Abeedullah Jan

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FUNDAMENTALS OF PHOTOINTERPRETATION AND PHOTOGRAMMETRY

BY

ABEEDULLAH JAN

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Preface

Aerial Forest Inventory Project which was established in 1965 has already published a number of publications. Of these, the Volume Tables have been published by the Pakistan Forest Institute and the others by Aerial Forest Inventory Project. The "Fundamentals of Photo-interpretation and Photo-grammetry" is one of these series.

2. Photo-interpretation technique has been introduced in the Forest Inventory and Land use Survey of Northern West Pakistan. With the emphasis that is being placed on watershed management, increasing use is likely to be made of these techniques, as basic tools for appraising the resources and the problems relating thereto. It was, therefore, logical to develop guide lines and training material in the form of a text book for professional and sub-professional staff of the Forest Service and allied organizations. Pakistan Forest Institute has introduced Aerial Forest Inventory as a regular discipline in the training courses of degree and diploma classes. This book can be utilized by them also.

3. Mr. Abeedullah Jan is to be commended for the presentation of the material on such a highly technical subject in an intelligible manner.

(M. HABIB KHAN, TQA)
Secretary to Govt. of N.W.F.P.
Food, Agriculture and Co-operation Department,
Peshawar.

Peshawar,
January 1, 1972.

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Introduction

The author had the opportunity to avail of a training facility in U.S.A. where he attended the University of Minnesota as a regular student of Master Degree in Science with major in Forest Inventory from September, 1966 till December, 1967.

2. This book was written by the author during his stay in U.S.A. under the guidance of Dr. Hugo H. John and Dr. Marle P. Meyer, his academic advisors at the School of Forestry, University of Minnesota, U.S.A. Later, it was re-shaped with photographs and illustrations from West Pakistan, keeping in view the training requirements of forest staff and students of the diploma and degree courses of Pakistan Forest College.

3. The book contains some reproductions from foreign publications. Permission, where necessary, has been obtained with the courtesy of the publishers. They are: the Ronald Press Company, New York, U.S.A. who granted permission to reprint certain passages and figures from "Photogrammetry and Photo-interpretation" by Stephen H. Spurr and "Forestry Handbook" by Society of American Foresters; and, the American Society of Photogrammetry for using material from their "Manual of Photographic Interpretation." The author sincerely appreciates and is extremely grateful for the courtesy extended by them in granting the permission.

4. The author offers his thanks to his academic advisors at the University of Minnesota under whose guidance this book was written. They spared no efforts to provide necessary guidance and help required at various stages of the preparation of this book.

5. The author is also grateful to the U.S.A. AID who sponsored his training programme.

6. Lastly, the author is also thankful to Mr. M. Habib Khan, TQA who read through this book and wrote a preface.

Peshawar,
January 1, 1972.

Abeedullah Jan

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AND

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Foreword

Photography had its first advocates in the army to know the disposition of enemy troops and the nature of the terrain; as a supplement to information from ground scouting. With the invention of the aircraft, photography even became more popular as it could provide information about areas which were otherwise inaccessible on the ground. This technique was used with considerable success by both the sides during the two World Wars. To negate the use of aircraft for such intelligence work, new techniques in camouflaging were developed. But the technical advances in photography countered these developments. A vehicle camouflaged by dead branches though could deceive a normal eye, yet could easily be made out on an infra-red colour film, on which live healthy vegetation appear red and dead vegetation green.

2. Those trained in photo-interpretation for the army, later in civilian life, thought of its use for various civilian purposes. One purpose which was overlapping both in the military and civilian spheres was mapping because maps were of use both to the army as well as non-army activities. This led to the development of the science of photogrammetry i.e., the preparation of maps through measurements on an aerial photographs. This technique produced more accurate maps, within much less time. Collaterally, the resource surveys effectively used aerial photography for identifying and locating different natural resources and with this developed the science of photo-interpretation.

3. The use of aerial photographs for both the above purposes were opposed by the proponents of ground surveys primarily for the fear that they may get out of employment because of the speed with which results could be produced by new methods or because of mere inertia, which is inherent in human nature: not to accept any change willingly. Both the apprehensions did not come true. It is now realized by all concerned that if only the techniques advocated by such stalwarts as Professor R. N. Colwell of University of California, at Berkeley had been accepted earlier, the intervening period of mere opposition could have served humanity much better, by production of necessary resource inventories for planning of development programmes and helped in removal or at least mitigate hunger which is threatning a large proportion of human race. The speed gave quick results and with the results came the exploitation of these resources for which more manpower is needed and therefore nobody could get out of employment. Aerial photographs are used in developed countries for intensive management of resources and in under-developed countries for locating the resources which are mostly un-known. Thus these are used both in extensive as well as intensive management.

4. Forest Service is one of the pioneers in this country to use this new technique for drawing up of forest inventories and integrated resource survey reports for preparation of development programmes. But it has been felt that there is no text-book readily available which could introduce the subject to those interested in learning it.

5. Mr. Abeedullah Jan while under-training in the University of Minnesota realized the necessity and started on a draft during his study at the University. He modified this draft in view of the practical experience and difficulties encountered in actual practice when he was posted to the Aerial Forest Inventory Project.

6. I compliment him on the way he has presented this new technique. Although it can be said that most of the material he has used is foreign but this cannot be helped because aerial photography as used in Pakistan is subject to strict security regulations and cannot, therefore, be reproduced. Further, the printing facilities available within the country are not so good as to enable a good reproduction of photographs which is very important because photography must maintain its detailed information in tones of grey to help in interpretation but this is very difficult if the quality of original photography is poor. He deserves all congratulations for writing this book which would serve as a good introduction to all those interested in learning this new technique of photo-interpretation and open new vistas to human experience.

(GHULAM AHMAD)
Conservator of Forests.
Aerial Forest Inventory Project,
Peshawar.

Peshawar.
July 20, 1971.

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I

Aerial Photographs

Aerial photography is extensively used in forestry, engineering, geology, soil science, agriculture, range management, wildlife, urban planning and many other allied fields in countries like the United States of America, Canada and Great Britain. In forestry, it is used in many operations such as mapping, surveying, inventory, timber management, boundary location, road alignment, identification and delineation of vegetation types, area measurement and disease detection. In fact, aerial photography is an essential component of space-age forestry because of speed, economy, accuracy and availability of certain information which is difficult and un-economical to collect by routine and conventional methods. The forester of today is increasingly convinced of these benefits, and, is therefore, willing to make greater use of aerial photos and put greater reliance on photo-interpretation and photogrammetry.

Among developing nations, Pakistan is one of the pioneering countries which has introduced photo-interpretation techniques into forest inventory and land-use surveys in the northern part of West Pakistan. Since a large number of professional foresters who are not well-versed with photo-interpretation techniques would be required to work in this new project, it is necessary to develope some guide lines for understanding the vast field of photo-interpretation and photogrammetry. This book is a modest attempt to achieve that objective.

Photo-interpretation and Photogrammetry

Photo-interpretation deals with the examination of photographic images for the purpose of identifying objects and deducing their significance. Everyone, to a certain degree, is a photo-interpreter. However, photo-interpretation as practiced by a professional forester, requires a solid background of training and experience, otherwise he is liable to overlook or misinterpret small and subtle features on aerial photographs.

Photogrammetry is slightly different from photo-interpretation. It is defined as the science of obtaining reliable measurements of objects from their photographic images. Measurements of tree heights, measurement of slope, determination of direction and measurement of photographic scale come under the domain of photogrammetry.

From the above, it may be seen that two types of information are generally obtained from aerial photographs as follows:

Objective. This includes the various kinds of spatial measurements,

such as location, direction, length, size, area and volume. This information is obtained through the knowledge of photogrammetry.

Subjective. This includes the personal conclusions and interpretations reached by the photo-interpreter on the basis of the above measurements and other information of a qualitative nature obtainable by use of the stereoscope.

Types of Aerial Photographs

Aerial photographs are of two types:

1. *Vertical.* Vertical photographs are those which are taken with a camera pointed down vertical (camera axis horizontal) or as nearly vertical as possible in a flying and vibrating aircraft. Since vertical aerial photographs are most commonly used in modern aerial photogrammetry and photo-interpretation, the term "photograph", unless otherwise specified, refers to a vertical aerial photograph as illustrated in Figures 1 (a) and (b).
2. *Oblique.* Oblique photographs are those which are taken with a camera pointed obliquely (camera axis directed between horizontal and vertical). Oblique photographs are further classified into two categories:
   a. *High Oblique.* High oblique are those photographs in which the horizon is visible. This is illustrated in Figure 2 (a).
   b. *Low Oblique.* Low oblique are those photographs in which the horizon is not visible although its position can be recorded on the film by means of mirror attachment. This is illustrate in Figure 2 (b).

The terms "high" and "low" do not refer to the elevation of the aircraft, but they refer to the angle of the tilt of the photographs or the degree of deviation from the vertical.

Figure 3 illustrates the geometry of vertical, oblique and horizontal photographs.

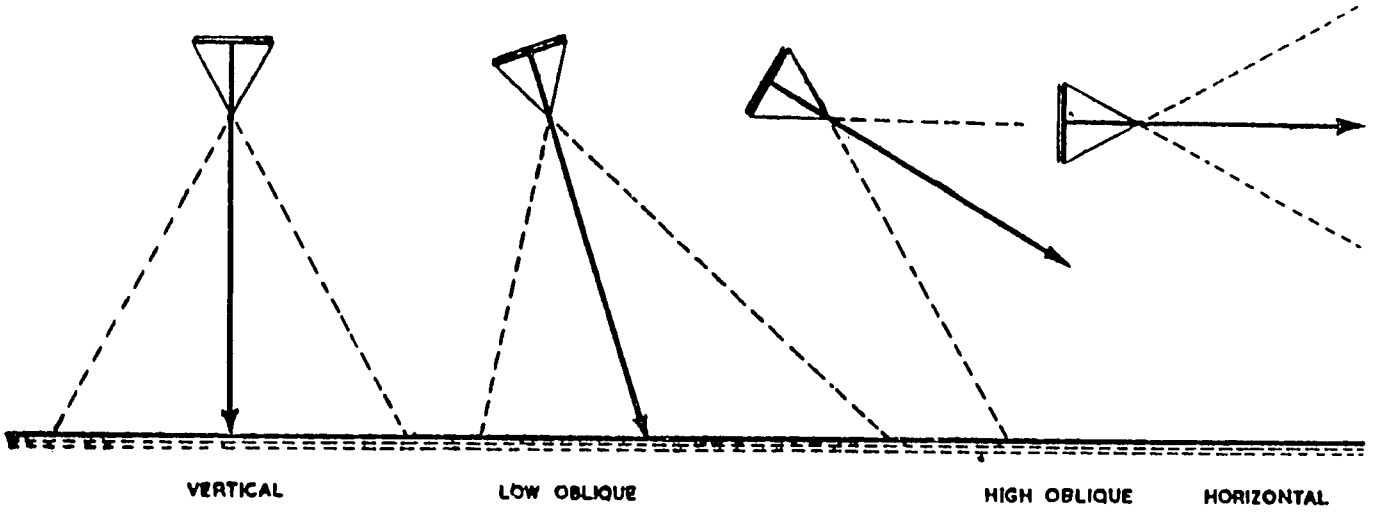


Fig. 3 —*Geometry of vertical, oblique and horizontal photographs.*

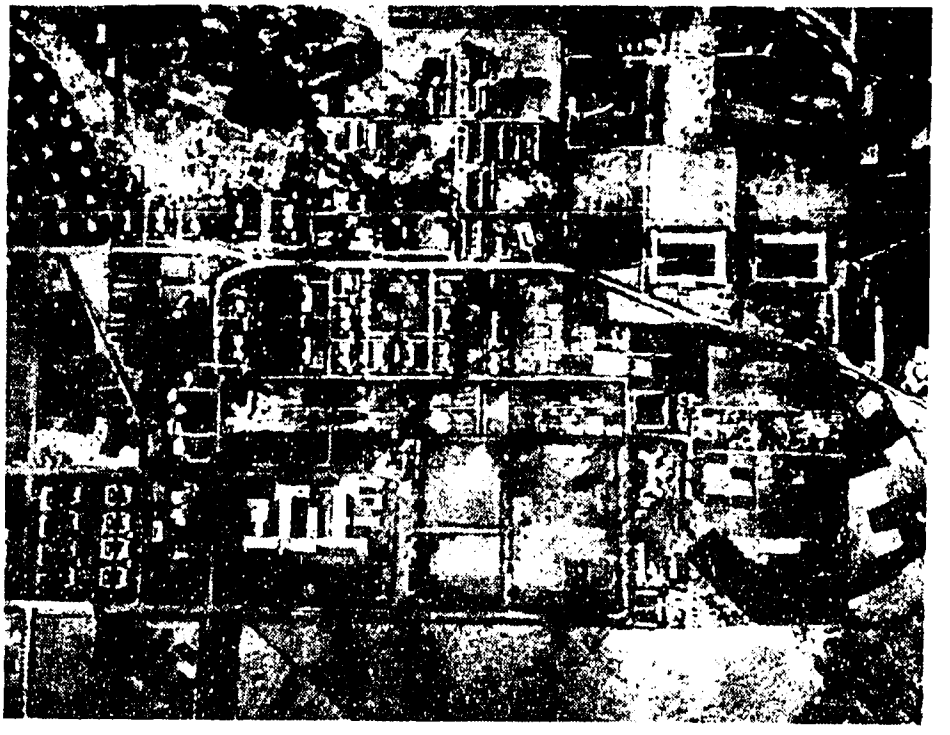


Fig. 1 (a) —*Vertical aerial photo of Pakistan Forest Institute, Peshawar.*

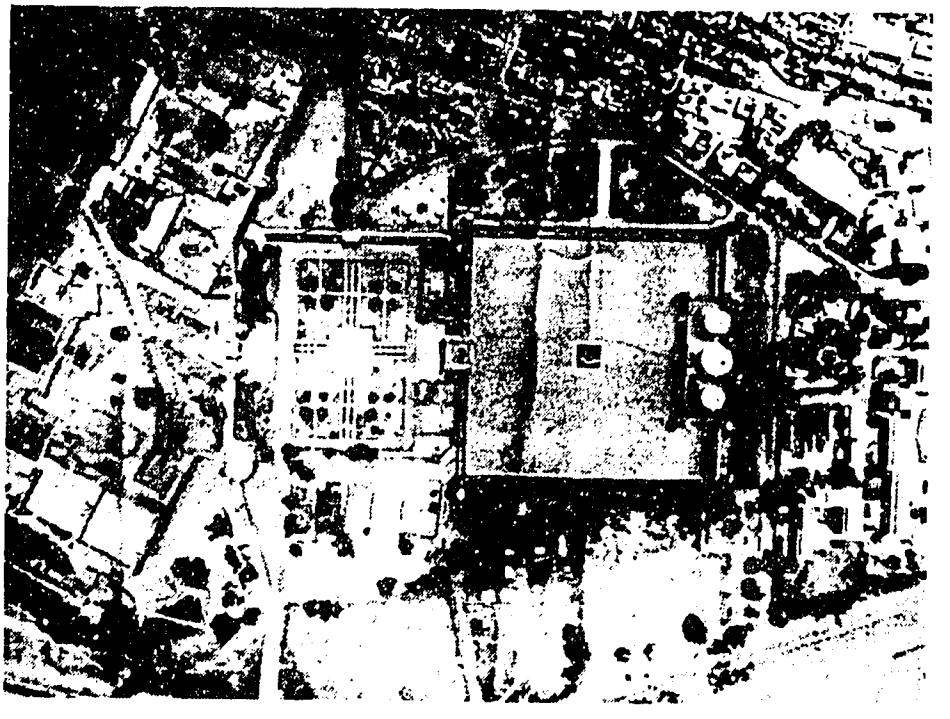


Fig. 1 (b) —*Vertical aerial photo of Badshahi Mosque and a portion of Lahore Fort.*

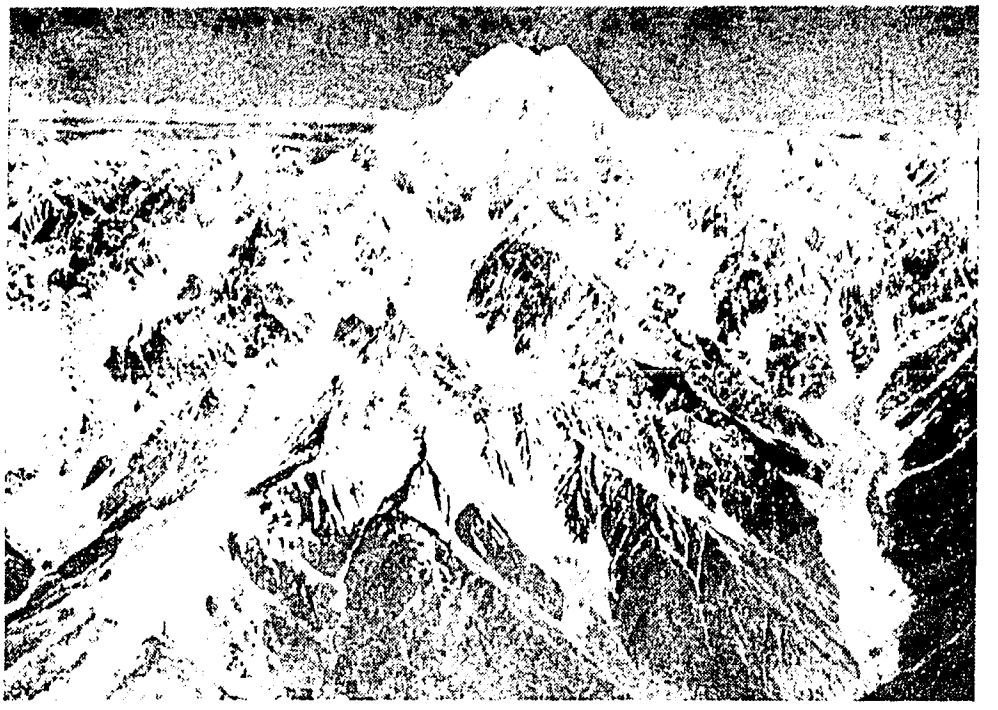


Fig. 2 (a) —*High oblique aerial photo of Trich Mir, Chitral.*
(*This photographs was taken with greater angular deviation from vertical and therefore horizon is clearly visible*).

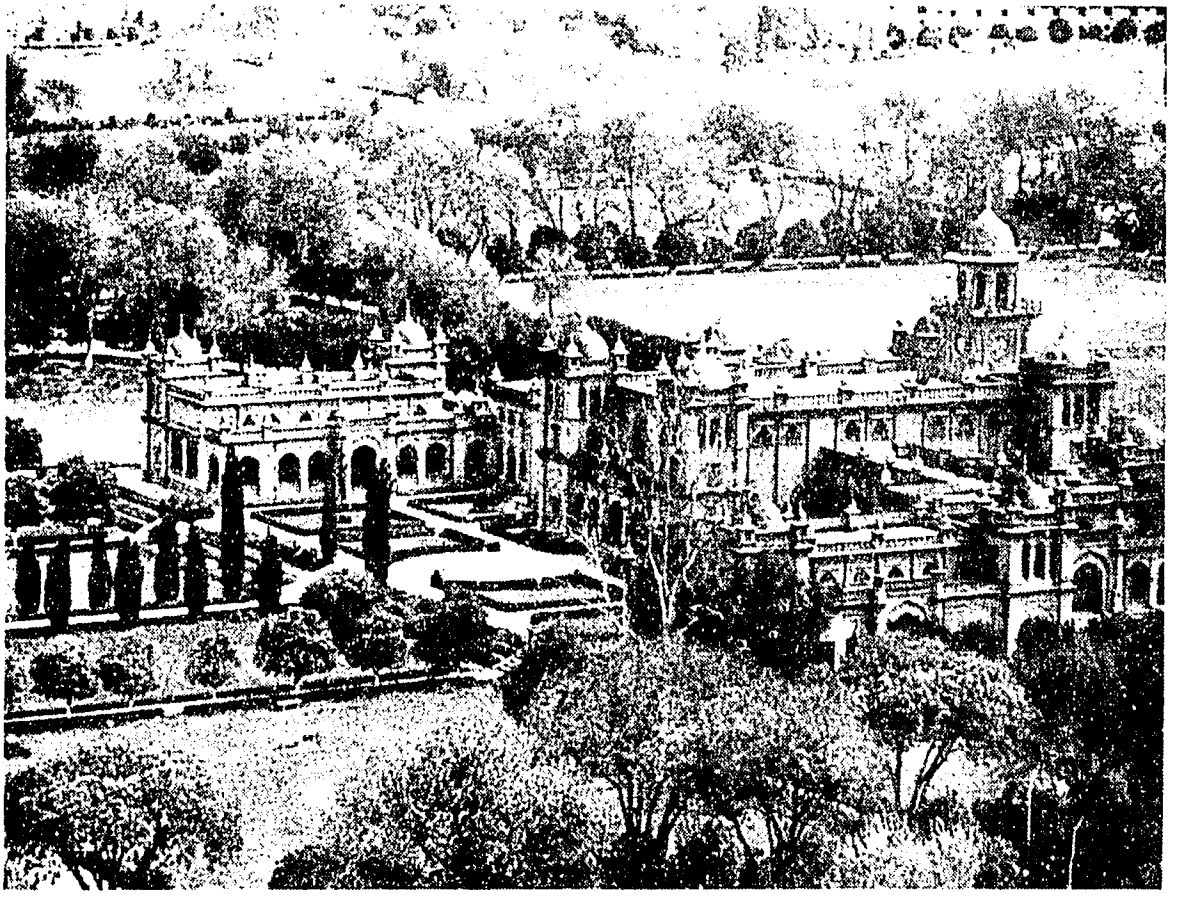


Fig. 2 (b) —*Low oblique aerial photo of Islamia College, Peshawar.*
(*This photograph was taken with lesser angular deviation from vertical and therefore horizon is not visible*).

Centre of the Photograph

In the discussion that follows, reference is made frequently to the centre of the photograph. Since the term "centre of the photograph" conveys different meanings under different situations, it is necessary to explain and define all these terms which refer to the centre of the photograph. They are:

Principal Point. The principal point is the optical or geometrical centre of the photograph. It is found by reference to the fiducial marks which are indicated on the photograph.

Nadir. Nadir is the true centre of the photograph. In other words, nadir is that point where a perpendicular from the ground through the centre of the camera-lens intersects the film plane. The position of the nadir on the photograph is important because topographic displacement is a function of the distance of the displaced images from the nadir and this displacement is always in line with the nadir either towards it or away from it. In other words, topographic displacement is always radial from the nadir.

Iso-centre. Iso-centre is a point on the axis of tilt and lies approximately halfway between principal point and nadir on the photo. The isocentre is a focus of tilt displacement, the latter being a function of the distance to the isocentre and is radial from this point.

Figure 4 illustrates the location of principal point, nadir, isocentre and fiducial marks on the aerial photograph.

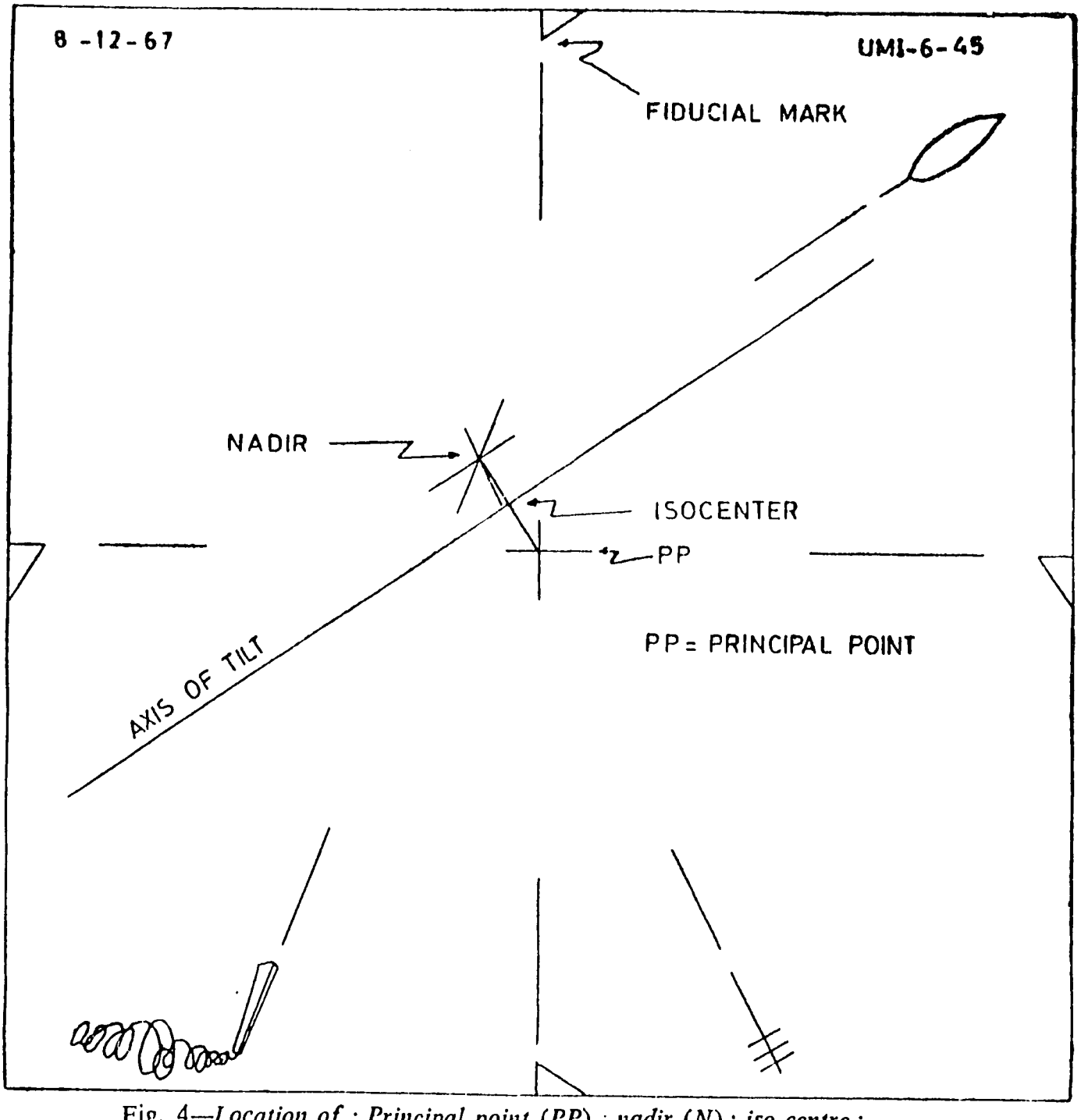


Fig. 4—*Location of : Principal point (PP) ; nadir (N) ; iso-centre ; and fiducial marks on aerial photograph.*

II

Principles of object recognition

Photo-image Characteristics

It is easy to recognize objects by looking at horizontal or oblique photographs, but difficulty is experienced when we examine objects on vertical photographs taken from several thousand feet above ground level. On such photographs, tall objects like trees appear as black dots. Distinction between roads, canals and railway lines is sometimes difficult to make. A foot ball stadium or a cricket ground may be confused with a drive-in cinema. Because of these difficulties, the photo-interpreter is required to develope the power of keen observations combined with patience and judgment to correlate various clues and to draw correct conclusions through a logical process of thoughts and mental acuity. Some of the clues or photo-image characteristics are shape, size, tone, pattern, shadow and texture.

Shape

Shape refers to the outline appearance of an object on a vertical photograph. Every object has its own geometric shape which alone may serve to identity that object. For example, it may be easy to recognize a football stadium because of its rectangular shape. Likewise topographic features such as hills, valleys and cliffs, vegetational features such as tree and grassland, cultural features such as buildings and roads are generally recognized from their three-dimensional shape. The differentiation between trucks and cars can easily be made on the basis of their characteristic shapes and relative and absolute sizes.

Size

The size of an object is one of the most useful clues to its identity. For this purpose both relative and absolute sizes are important. For example, it is easy to recognize a car and a truck on an aerial photo because of their absolute and relative sizes. Absolute size is a function of the photographic scale. The same object would appear smaller on a photographic scale of 1:20,000 as compared to a scale of 1:10,000, but the geometric shape of that object would remain the same. For the purpose of object identification, both size and shape are considered together. For example, a road is identified on an aerial photograph by its trailing shape, but the differentiation between a highway and a narrow village road is made on the basis of their relative width.

Tone

Photographic tone is defined as a relative lightness and darkness of photo images. Certain objects register light tone while others register dark tone on photo prints because of their different qualities of light reflection. Objects that

reflect sunlight are photographed light in tone while objects that absorb light are photographed in dark tones. Smooth surfaces such as lawns, roads and soil (mineral) are generally registered in light tones. Rough surfaces such as agriculture crops, forest trees, and organic soils are registered in dark tones (Figure 5).

Since photographic tone is influenced by many complex factors, photo-interpretation based upon direct tonal contrast is subject to considerable error. Some of the factors which determine or influence photographic tone are:

(i) Light reflectivity of the object.
(ii) Light sensitivity of the film.
(iii) Light scattering by atmospheric haze.
(vi) Light transmission by the filter used.
(v) Angle of the elevation of the sun.
(iv) Position of the object on the ground.

When the photo-interpreter understands these factors that govern photographic tone, he is able to recognize these characteristics as major clues to the identity of objects or their composition. For example, the forester uses tonal variations to distinguish hardwoods from coniferous stands and the soil scientist classifies soils on the basis of tonal contrast of different soils.

Pattern

Pattern refers to an orderly and spatial arrangement of objects. Fruit trees growing in an orchard exhibit a definite arrangement and a regular pattern which is readily distinguished from irregular growth of trees in a forest (Figure 6). Trees growing along a roadside or a canal bank have a different pattern than those growing elsewhere. By looking at the growth pattern, it can be readily concluded whether trees are nature-grown or man-planted. Similarly, a road and a railway line may look very much alike on aerial photographs, but a photo-interpreter can differentiate between the two by configurational pattern. A road may have a fairly steep grades, sharp curves and many intersections, but in contrast, a railway line has gentle grades, wide curves and few intersections.

Shadow

Shadow is defined as a mirror image or profile image of an object. Since shadow is the true image of the object, it is considered helpful in direct identification. Many objects such as electric poles, fire towers, radio antennae and forest trees are difficult to identify directly on vertical photographs. All such objects are recognized from their characteristic shadows cast by them as illustrated in Figures 7(a) and 7(b). Shadows are particularly helpful in identifying tree types such as conifers which generally have pointed tips and hardwoods which generally have rounded tops.

Shadows also present some difficulty in photo-interpretation by obscuring ground detail. Much of the ground detail is lost in shadow, particularly on the shaded sides of steep hills, high mountains and dense forest stands.

Texture

Texture is defined as the frequency of tonal change within photo image.

Fig. 5—*Stereogram showing difference in tone on aerial photograph. (Forest trees have been registered in dark tone whereas road and mineral soil have been registered in light tone.*

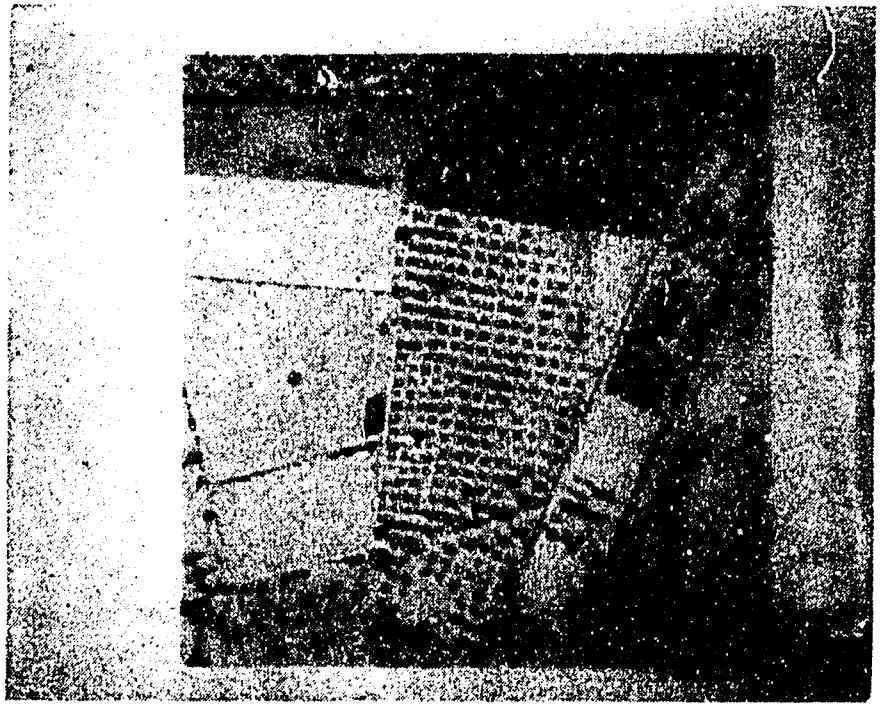


Fig. 6—*Photograph illustrating the importance of pattern in object identification. (Note the regular pattern of fruit trees in an orchard as against the irregular pattern of forest trees under natural condition).*

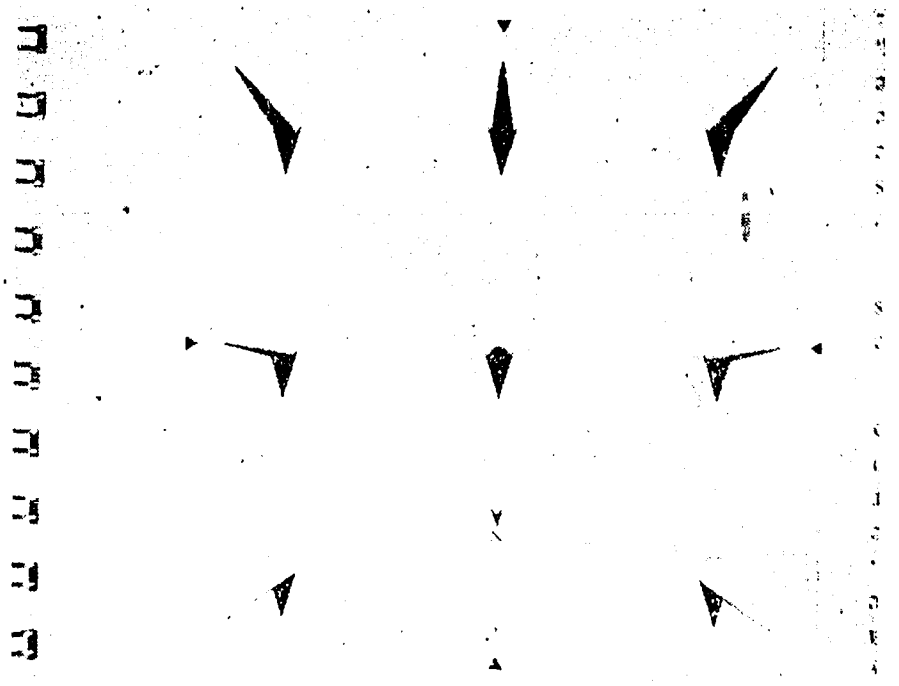


Fig. 7 (a)—*Characteristic shadows of similar objects with 60° altitude at noon. (Note the difference in shadow due to location/position of the object on the photograph).*

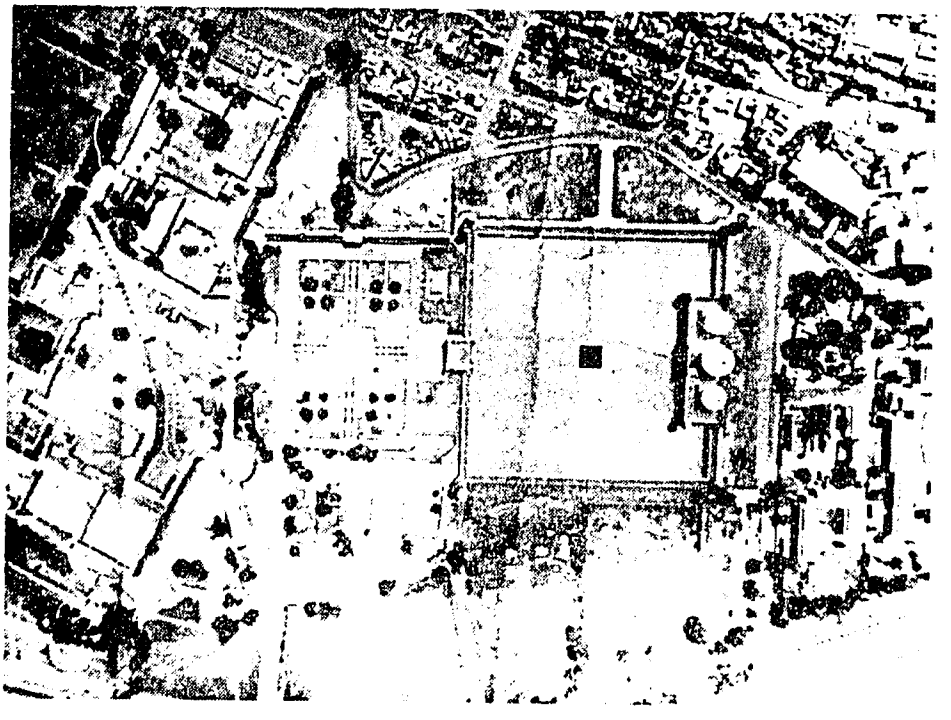


Fig. 7 (b)—*Characteristic shadows of minaretes of Badshahi Mosque, Lahore.*

Texture is produced by an aggregate of unit features individually too small to be clearly discernible on the photograph. For example, a tree is visible on an aerial photograph, but the individual leaves or needles may not be visible, but they still contribute to the texture of the tree crown as a whole. In photographs of smaller scale i.e. 1.30,000, the individual trees may not be visible, but their crowns contribute to the texture of the stand as a whole.

Although photographic tone is the basic element of texture, the conditions that affect photographic tone may vary yet the texture may still be a diagnostic element. This is due to the fact that texture in the photographic sense is a composite of several fundamental characteristics; namely, tone, shape, size, pattern and out of these elements, slight variations of tone would unlikely affect the overall photographic texture to a significant level.

Photographic textures have been described by various research workers as coarse, fine, rough and fluffy, but such descriptive terminology would seem to have very limited use or benefit unless photographs of coarse, fine and fluffy texture are observed with naked eyes.

Factors helping in Photo-interpretation

The process of photo-interpretation in forestry is made easier by taking advantage of the factors such as field control, knowledge of area, knowledge of the subject, field of view and radial displacement.

Field Control

Field control is necessary for most of the forestry operations and photo-interpretation is no exception to this rule. The information collected from aerial photographs in the office must necessarily be checked with the actual conditions in the field by paying visits to the field for observations. Such observations are not only important but also helpful to the interpreter to arrive at reliable conclusions from interpretation over a large tract of forestland.

Knowledge of Area

The interpreter should be familiar with the area and he should have adequate knowledge of the geographic and physiographic distribution of the tree species and the influence of site on the species association. If he is not equipped with the knowledge of the area and species distribution, he is more likely to commit mistakes and his interpretation would probably be unreliable. For this reason, topographic location of the objects and their association with a particular landscape feature are very important for the purpose of identification. This is particularly important because a single feature like size, shape and pattern by itself may not be distinctive enough to permit its identification. Chir pine (*Pinus roxburghii*) and blue pine (*Pinus wallichiana*) may produce identical crown shapes, shadow pattern, tone and texture, and therefore, it may be difficult to identify them unless their locations are known because these species grow in definite elevation zones. In majority of cases the vegetation types are identified on aerial photographs by their association with topographic locations.

Knowledge of the Subject

Knowledge of the subject is a pre-requisite for correct identification. A man

who is able to identify a particular tree on a vertical photograph should necessarily be familiar with leaf shape, branch habit and crown pattern of that particular tree. An individual thoroughly familiar with all the aspects and associations of an object is the person best able to identify that object on aerial photographs.

Field of View

On medium scale photography, e.g., 1:15,840, a simple lens stereoscope with double. (2ˣ) magnification permits the interpreter to view a considerable area of the photograph at one time. This readily permits comparison of several stand groups and speeds up the process of interpretation.

Radial Displacement

Increase in radial displacement is directly proportional to the distance of the object location from the centre of the photograph. In other words radial displacement is maximum along the margins of the photograph and minimum near the centre (PP). A tree located near the centre of the photograph would appear like a black dot, but the same tree if located along the margin of the photograph would appear more in sideview due to radial displacement as illustrated in Figure 8. Since tree profile is more familiar and since each species has a characteristic profile visible through radial displacement, the latter is considered a valuable aid in species identification.

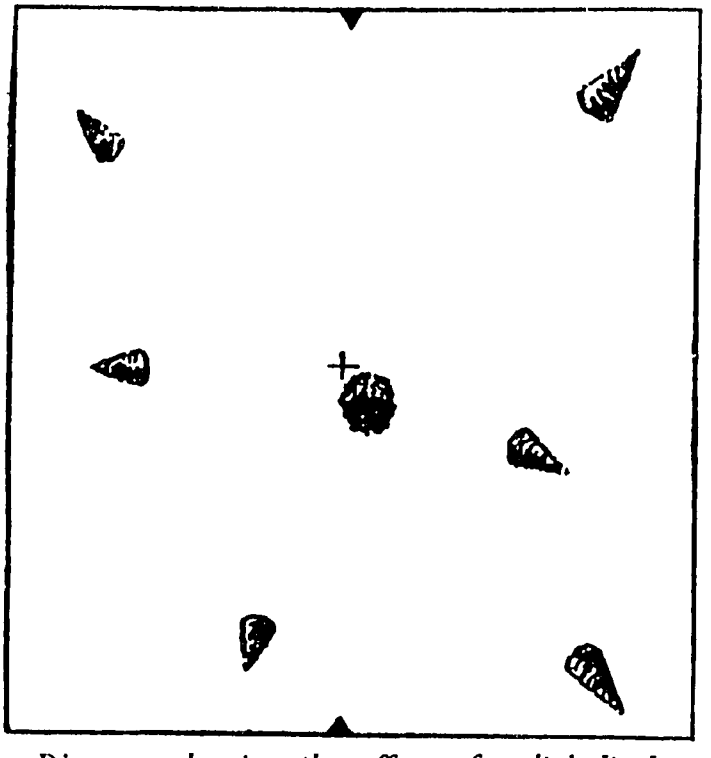


Fig. 8—*Diagram showing the effect of radial displacement.*

Factors Hindering Photo-interpretation

The process of photo-interpretation is hindered by factors such as shadow point, area of maximum shadow, effect of sun altitude and effect of light.

Shadow Point

Shadow point is also called *no-shadow point*. *Hot spot* is another name commonly used for it. This is a point where the relief displacement of objects exactly matches the shadows with the result that no shadows are visible. This point falls at a place where projection of sun's rays after passing through nodal point of the camera lens strike the ground. Since the sun and the aircraft taking photographs are exactly in line at this point, the shadow of the aircraft may often be registered on the photograph if the aircraft is flying at a low altitude.

If the no-shadow point falls on the photograph, a hot spot is created in which the photographic image is very light and over-exposed. Owing to halation, the photographic detail in this area is considerably less than in any other part of the negative. Furthermore, owing to the absence of shadows, the image has a washed-out appearance and is therefore, difficult to interpret stereoscopically. (Figure 9). As a result, about 3 per cent of the stereoscopic model may be lost both for mapping and photo-interpretation. Since electronic printers have become available, the effect of uneven density can greatly be reduced in the prints. The process is known as "dodging" (Figure 10).

Area of Maximum Shadow

Photographs are relatively darker on the western, southern and eastern sides, depending on the time of the photography. The camera records the greatest proportion of shadow accentuated by glare in areas facing away from the sun. Uneven illumination is illustrated in Figure 9, which represents an undodged aerial photograph showing areas of maximum and minimum shadows. The area of maximum shadow is sometimes called as solar reflection point. The solar reflection point and the no-shadow point are equidistant from the nadir (N) in opposite directions along a course that is oriented with the shadow of a vertical object (Figure 11).

Effect of Sun Altitude

The lens of the photographic camera records the image of the landscape according to the geometrical rules of central projection. Therefore, in vertical aerial photography, the objects appear differently from the truly orthogonal position at the nadir point (N) to the extremes of radial displacement at the corner due to variation in sun altitude. The parallel sun rays produce shadows of all objects in their path. This situation results in a tremendous variety of patterns in textured objects particularly trees, which may be further modified by topographic relief.

Effect of Light

The sun angle has the added effect of disturbing or altering the appearance of the same objects from one photograph to another. This phenomenon is illustrated in Figure 12 which is a stereo-triplet of the same area and covered by a stand of aspen (*Populus tremuloides*). The stereo examination reveals a difference in the appearance of the individual tree crowns when comparing the right stereo set with the left. Changes such as this in the appearance of the same object are the result of fore, side and back lighting. The left side photograph shows the same trees in back lighting. middle photograph in side lighting and right side photo-

graph in front lighting. The difference in photo's tone and texture due to difference in light intensity is quite apparent.

The photo-interpreter should be familiar with this natural phenomenon and avoid where possible identification on stereo-pairs featuring side and front-lighting. A combination of back and side-lighting reveals the most characteristic shape of individual tree species for the reasons explained as follows:

a. *Back-lighting*

In back-lighting, the image of a tree consists of a shaded area surrounded by a high-lighted portion of the crown which distinguishes the outline of the crown. In addition, the bright crown contour stands out against the dark background (the shadowed side of the adjacent tree) and provides a comfortable perception of relief with the stereo combination in side lighting. (Figure 13).

b. *Front-Lighting*

Front-lighting causes an excessive lack of contrast in the crown texture and its immediate surroundings through the reduction in shadow patterns. The image is flat and the feeling of relief is not readily apparent. Although the outline of objects appears sharp, the change in characteristic features hinders identification. The fact that even the spherical aspen may seem pointed under stereoscopic examination is due to the combination of a sharp outline of the crown which lacks detail and the exaggerated vertical scale. This effect is common particularly on photographs taken in a relatively low sun altitude. (Figure 13).

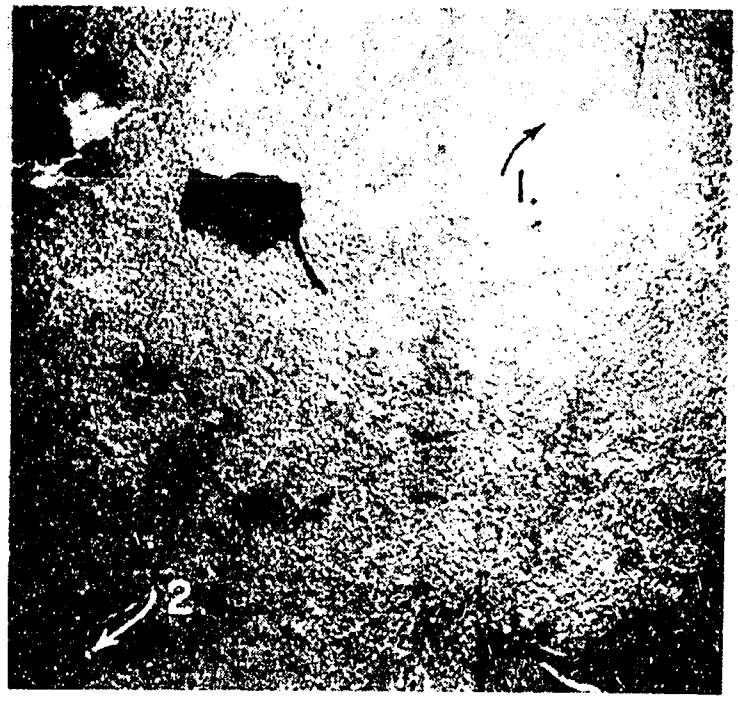


Fig. 9—*Undodged aerial photograph showing the shadow point at* (1) *and the darkened opposite side at* (2) *which is also the area of maximum shadow.*

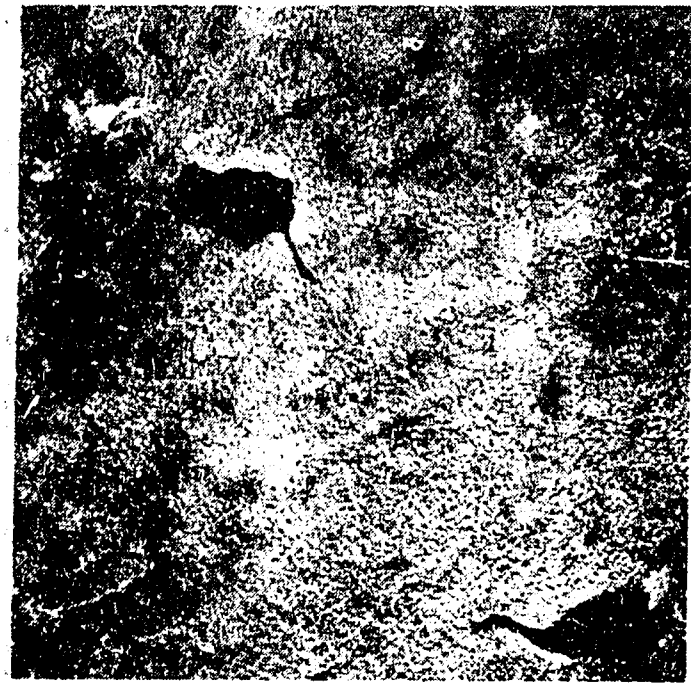


Fig. 10—*Aerial photograph dodged on automatic exposure control printer* (*from the same negative as in Figure* 9).

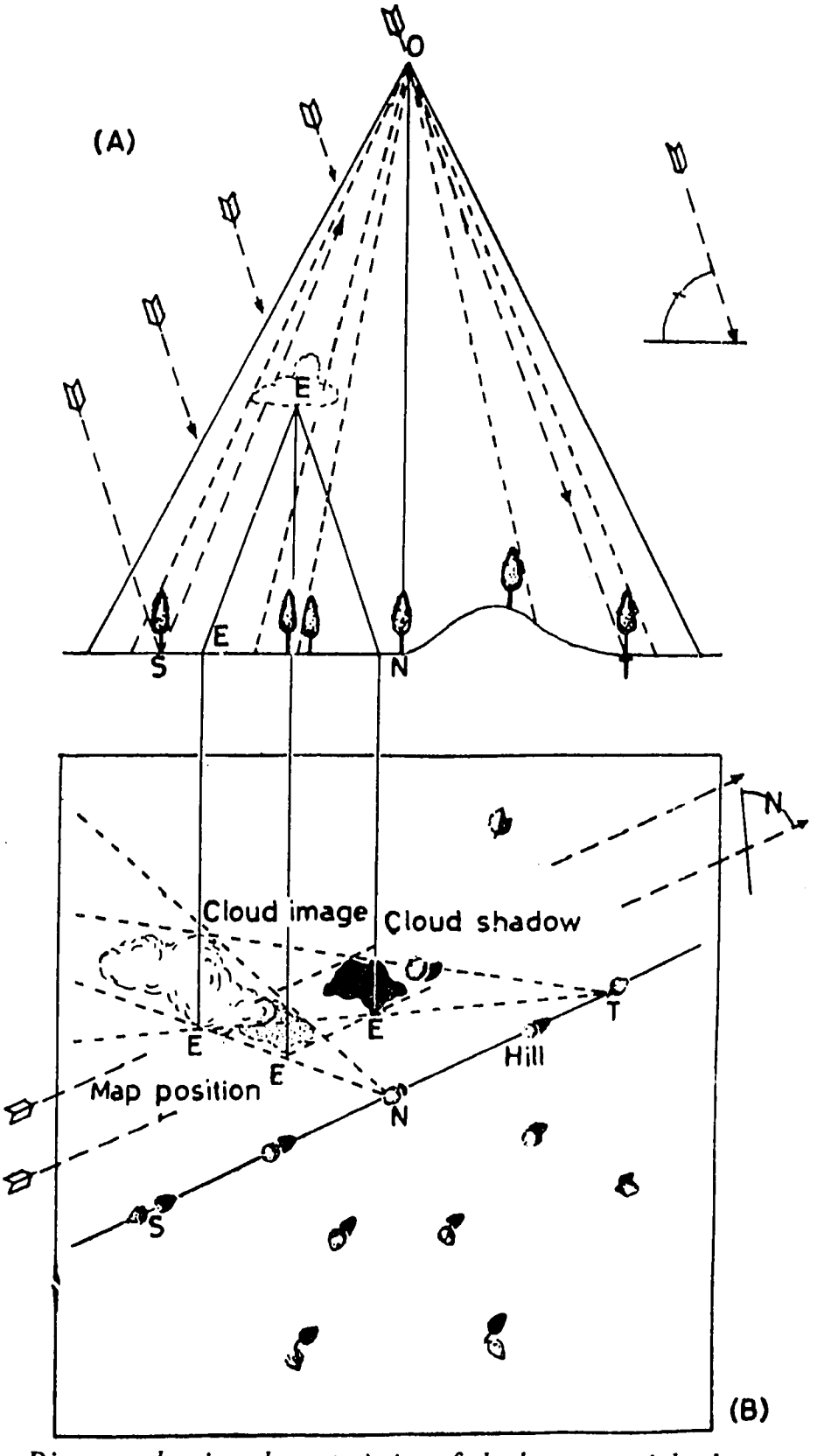


Fig. 11—*Diagram showing characteristics of shadow on aerial photograph. The direction of the sun's rays is shown by arrows on both the profile and plan views. The position of solar-reflection point (S), the nadir (N) and the no-shadow point (T) have also been shown. Also, note the radial displacement of the tree images in the plan view.*

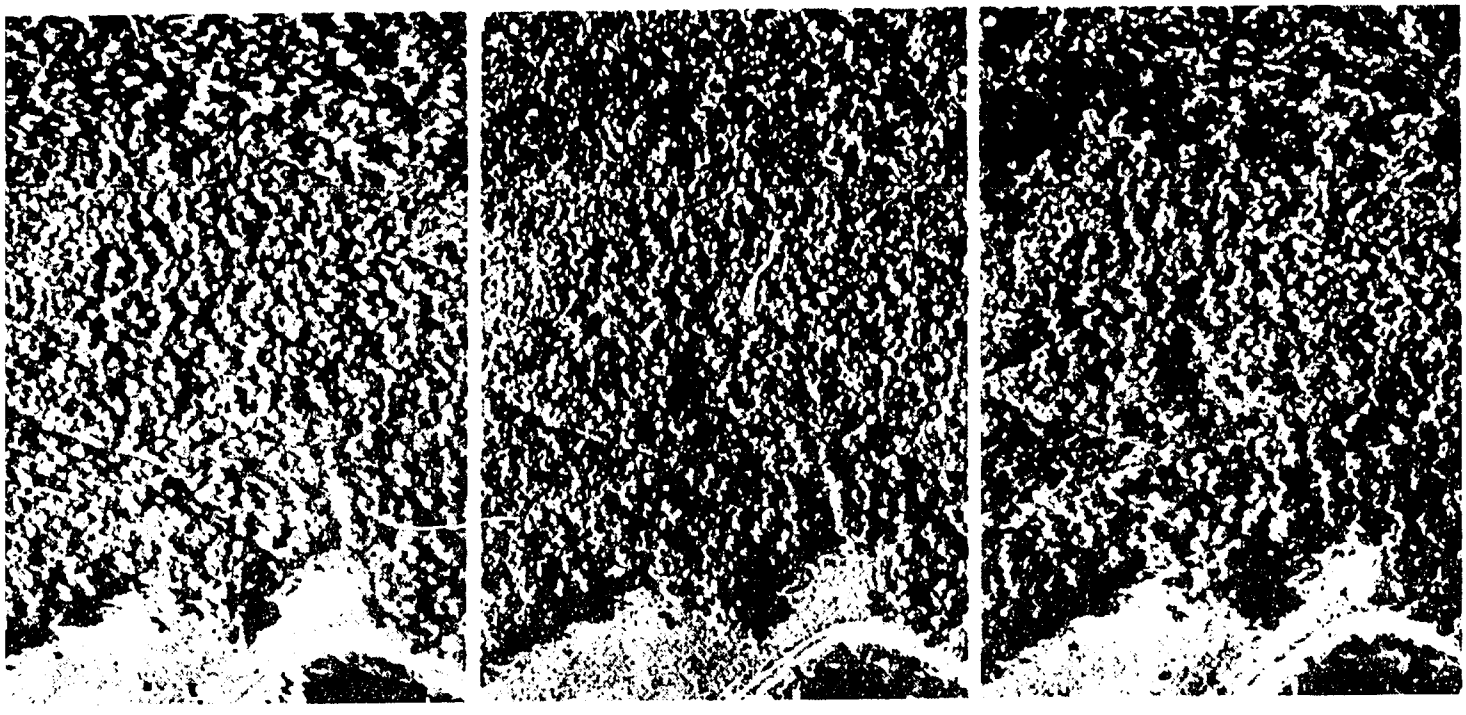


Fig. 12—*Stereo-triplet showing the effect of light on crown appearance.*

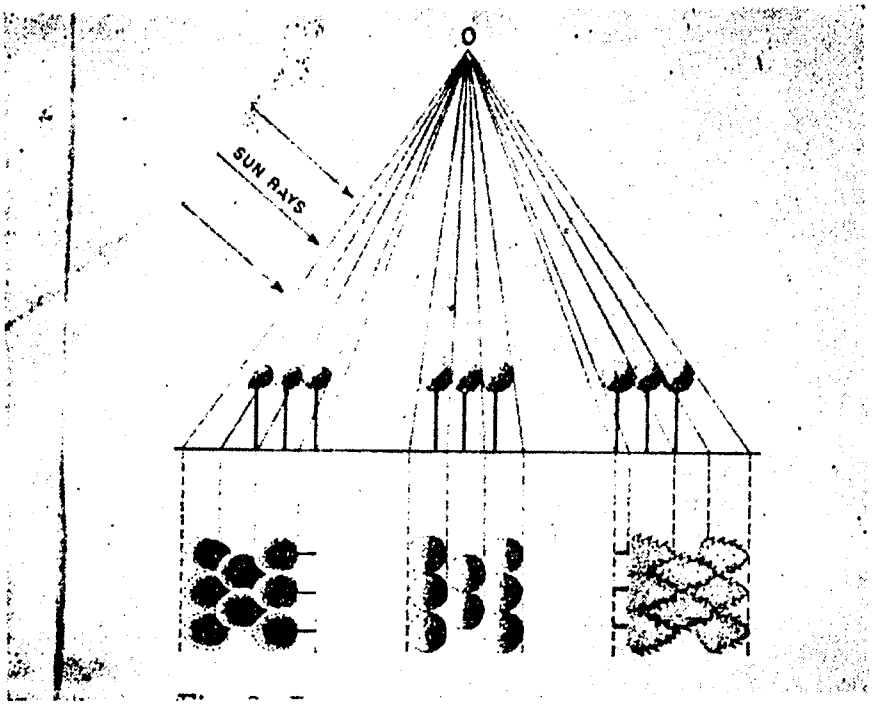


Fig. 13—*Diagram illustrating the principle of light effect on an aerial photograph.*

III

Photos: Types, Variations and Characteristics

Types of Prints

Aerial photographs are used for different purposes depending upon photo scale and ground relief. The scale of photographs varies because of variation in local relief, flying height and camera tilt. If the photographs are to be used for special purposes such as mapping, they would require special treatments. On this basis, the aerial photographs are grouped under five main categories. They are:

1. Contact prints.
2. Enlarged or reduced prints.
3. Rectified prints.
4. Ratioed prints.
5. Mosaic.

Contact Prints

Contact prints are those which are directly taken or produced from negatives either on paper or transparent base. They are used as such and no special treatment is given to them. They are made without the use of a projector, and therefore, they are at the same scale as the negative except for paper shrinkage. Provided the usual specifications are observed, these prints are well suited for most uses and are the least expensive type of prints used in forestry.

Enlarged or Reduced Prints

Sometimes, the prints are enlarged or reduced in order to meet special requirements. Aerial photographs can be enlarged four times and yet produce images of high pictorial quality. Enlarged photographs are commonly used as office records and important information such as boundaries, regeneration area, roads, etc., can be stored directly on these prints. Similarly photographs can be reduced to facilitate storing.

Rectified Prints

Photographs are generally taken with the camera axis tilted slightly since a perfectly vertical position can seldom be attained in a moving and vibrating air-craft. If the amount and direction of tilt is known, rectified prints can be produced by creating an appropriate compensating tilt between the negative and the printing paper. Rectified prints, therefore, are photographs corrected by removing angular displacement due to tilt.

Ratioed Prints

Because of variation in the flying height and ground relief the average scale of the photographs may vary considerably in even a single flight strip. When the prints are photographically enlarged or reduced to a common average scale, they are said to be ratioed.

Mosaic

Besides the above main categories of prints, there are other types of pictures which are called mosaics. The mosaics are pictures made by assembling a number of photographs. The assemblage is usually re-photographed and may be reprinted at any scale. In the strictest sense, a mosaic is an assemblage of photographs whose edges have been cut and carefully matched to form a single, continuous photographic representation. The main types of mosaics are:

a. Index mosaic.
b. Un-controlled mosaic.
c. Semi-controlled mosaic.
d. Controlled mosaic.

Index Mosaic

Index mosaic is a very rough mosaic, prepared for the primary purpose of providing an index to the individual photographs (Figure 14). The margin of each photograph in an index mosaic is clearly labelled so that the observer can quickly determine which photograph covers a particular area of ground.

Un-controlled Mosaic

The un-controlled mosaic is a mosaic in which prints are laid together without being ratioed or rectified.

Semi-controlled Mosaic

If the ground control of the mosaic is limited, the mosaic is known to be semi-controlled.

Controlled Mosaic

If rectified and ratioed photographs are laid down over a control network, the assemblage is called a controlled mosaic.

Mosaics are prepared for all areas photographed because they serve the following purposes:

1. Mosaics are considered a map substitute and they may be used to control work where an adequate base map is not available.
2. Since a mosaic represents a compact and continuous pictorial representation of the area, it is convenient to consult and to locate areas with relation to each other.

Print Variations

Print variations are due to material, surface, weight, contrast and tone.

Material

Prints are of three types:

a. Opaque paper prints.

Fig. 14— *Index aerial photo mosaic of Tangi and adjoining areas in Peshawar district.*

b. Cronapaque prints.
c. Film positives transparencies (diapositives).

Positive prints from photographic negatives may be printed on transparent, translucent or on opaque media. Diapositives printed on glass are characterized by the least dimensional changes and the sharpest detail. Paper prints are the cheapest, and they are commonly used for routine photo-interpretation. Cronapaque prints are intermediate in quality between paper prints and diapositives. Positive film transparencies are comparatively costly, but they are superior to opaque prints for photo-interpretation.

Surface

The print surface and character of photographic papers are some of the important considerations in obtaining and handling aerial photographs. So far as print surfaces are concerned, they are of three types:

a. Glossy prints
b. Semi-matte prints
c. Matte dried glossy

Glossy Prints

The work "glossy" means smooth and shiny. In photo-interpretation, it means smooth luster or fine grain luster. These prints produce the sharpest detail, but they reflect glare and are difficult to write upon. They also develope emulsion cracks with excessive handling and are not suited to necessary bending under the lens stereoscope.

Semi-matte Prints

"Semi" means half and "matte" means dull finish which together means "neither very shiny nor very dull and coarse." These prints are desirable because they have a minimum glare, and the surface is not too smooth to mark or write upon.

Matte Dried Glossy

Matte dried glossy prints are preferable because they combine the good qualities of glossy and semi-matte prints. The prints are smooth and shiny yet the glare is not offensive. The surface is sufficiently toothed to be easily marked yet the prints retain high resolution quality and sufficient contrast. These prints are made on paper, but they retain dimensional stability.

Weight

On the basis of weight, photo prints are classified into two main categories:

a. Single weight prints
b. Double weight prints

Single Weight Prints

In this case photo prints are obtained on single weight paper. The prints

are less expensive and are much easier to handle under the pocket stereoscope as they are more flexible. They also take less storage space. They are, however, subject to curling and dimensional changes caused by variations in temperature and humidity.

Double Weight Prints

The prints obtained on double weight papers are stiffer, more durable and less susceptible to dimensional changes caused by variations in temperature and humidity. They are, however heavy, and require more storage space.

Contrast

Contrast refers to distinctness of tones as opposed to gradations in tones. Black and white are extremes of contrast. Photographs with very dark and very light tones have generally high contrast. The amount of contrast is determined partly by variations in the capacity of objects to reflect light and partly by the clearness of the atmosphere and by the photographic techniques used. Atmospheric haze scatters light and reduces contrast. Photographs taken on bright days have greater contrast than those taken on dull days. Soil when wet absorbs light, and therefore, the photographs are darker than when the soil is dry. Contrast changes from season to season but not uniformly from region to region. It can be increased or decreased by varying the exposure time or the time for developing film and by the paper used for making prints.

Tone

The tone of an image on a photograph depends on the amount of light reflected by the object that forms the image. Objects that reflect most of the light appear light on the photograph and those that reflect small amount of light appear dark. The amount of light reflected from an object depends upon:

(i) The nature and colour of the surface of the object.
(ii) The degree to which the object is exposed to the sun.
(iii) The angle of reflection from the object to the camera.

The smooth surfaces like roads, dry soil, etc. are photographed almost white from a wide range of camera positions because they reflect light in many directions. In contrast, forest vegetation, wet soil and water bodies register grey to dark tone on aerial photographs because they absorb greater quantity of light.

On photographs the tones are mainly shades of grey, but there may occur complete range from black to white.

Film and Negative Characteristics

Films and photo negatives have the following characteristics:

1. Speed.
2. Density.
3. Contrast.
4. Film base.

Speed

The term "speed of the film" refers to the inherent sensitivity of emulsion to

light. If emulsion is very sensitive, the film is said to be fast. Different films have different aerial exposure index (speed). Aerial exposure index of some of the commercially available films are given in Table 1.

Table 1. Aerial Exposure Index of some Commercial Films.

Films	A.E. index (speed)	Type
E k Double — X Aerographic	125	Panchromatic
E k Plus — X Aerographic	80	Panchromatic
E k Super — XX Aerographic	100	Panchromatic
E k Tri — X Aerographic	250	Panchromatic
E k Infra-red Aerographic	125	Infra-red

The films with an Aerial Exposure Index of 100 or more are said to be fast films and those less than 100 are slow films. The knowledge of a particular film's speed is essential to obtain a correct exposure. Slow films may require bright sunshine or artificial light for proper exposure, while faster films permit good pictures under minimal light conditions.

Density

Photo density is defined as the comparative amount of silver deposited by exposure and development in a given area. It is expressed in terms of the percentage of light passing through the area. Density varies from high to low.

Contrast

Negative and print contrast refers to the amount of difference between the greatest and the least density. The contrast of photographic materials is not synonymous with "gamma." The latter does not include areas of under-exposure or over-exposure, while a true contrast rating must consider the total range of densities.

Film Base

Film base is a thin, flexible and transparent sheet of cellulose nitrate or acetate or similar material which is coated with a light-sensitive emulsion and is used for taking photographs.

IV

Film, Filter and Season

In order to obtain the maximum detail from aerial photographs, it would be necessary to procure photographs which combine the maximum image sharpness with the optimum tonal contrast between dissimilar objects. Among the many variables which influence the quality of the photographs, the following are important:

1. Light source.
2. Reflectance by the objects photographed.
3. Atmospheric haze.
4. Filter.
5. Film emulsion.
6. Development technique.

Based upon the above factors, the selection of right type of material and proper season of photography are important for obtaining best results. The quality of photographs depends upon:

1. Selection of film.
2. Selection of filter.
3. Season of photography.

Film

Photographic film is ordinarily composed of three distinct layers, namely, film base, emulsion and anti-halation backing. The film base is a cellulose acetate base coated on one side with a light-sensitive layer known as emulsion and on the other side with anti-halation backing which is an absorbing dye that prevents the formation of halos (ghost image) around bright images.

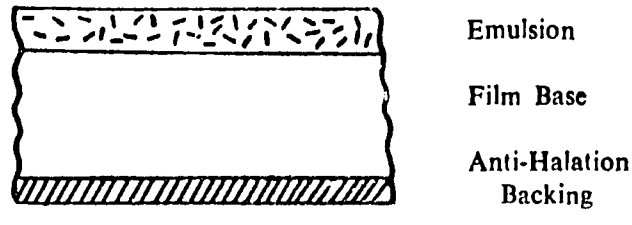


Fig. 15—*Cross-section of photographic film.*

A large variety of films are available for obtaining aerial photographs and still more are being placed on the market through constant research. Most commonly known are the black-and-white and coloured films.

Black and White Films

There are two types of black-and-white films :

a. Panchromatic
b. Infra-red

Panchromatic Film

Black-and-white Panchromatic picture appears "normal" to the human eye because it registers the entire visible spectrum, approximating the range of sensitivity of the human eye. Since it is a fast film, and is sensitive to a wide range of colours, it is widely used for photo-interpretation. The quality of the finished pictures, as with all films, depends upon the time of exposure, the developer used, the time of development, the temperature of the developer and the photographic characteristics of the emulsion used for the positive prints. Tonal differences between the objects on panchromatic films can be increased by slight over-exposure of the positive.

In short, both standard speed Super-XX and Double-X Panchromatic films provide a reasonably good tonal contrast, a wide exposure latitude, satisfactory resolving power and low graininess. Thus, they are superior to all other black-and-white films for distinguishing objects of truly different colours, but their lack of high sensitivity to green light makes separation of vegetation types (conifers and broadleaved species) rather difficult.

Infra-red Film

The term "infra-red film" is applied to any film that has been sensitized to infra-red radiation. The photographs taken on infra-red films are different from photographs taken on other black-and-white films. Green colouring matter of leaves, (chlorophyll), has a very high reflectance in infra-red and therefore, the infrared portion of the light spectrum is reflected by the leaf tissue instead of being absorbed by the chlorophyll. That means that most foliage will register in lighter tones on infra-red film than on any other black-and-white film. Only vegetation having foliage and structure of such a nature as to absorb infra-red light will register in dark tones. For example, broadleaved vegetation is highly reflective, and therefore, photographed in light tones whereas conifers or "needle-leaf vegetation" tends to absorb infra-red radiation and consequently registers in darker tones (Figure 16).

Figure 17 illustrates comparison between panchromatic and infra-red photos.

Coloured Films

The potentialities of colour photography for aerial photo-interpretation impresses virtually everyone who has seen a good colour aerial photograph. But up to the present time, the problems of cost, proper exposure and development, haze and image sharpness have limited the actual application of colour photography in aerial photo-interpretation to research and disease detection in forest trees.

Like the black-and-white film, coloured film can also be of the panchromatic or infra-red type. Various firms have developed coloured films of different qualities with their own trade names. Eastman Kodak Company have developed the following coloured films:

a. Kodak ektachrome aero film.
b. Super anscochrome.
c. Kodak aero ektacolour (negative) film.

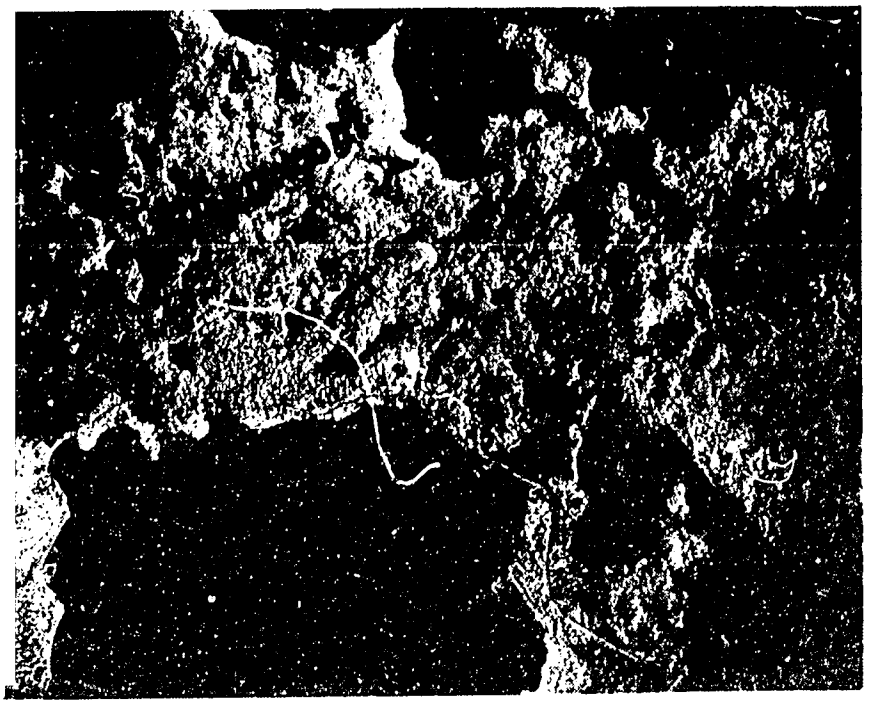


Fig. 16—*Normal infra-red photo (infra-red film exposed through 89 filter). Note the excessive contrast between hardwoods and conifers. Hard-woods are white but conifers are dark to black.*

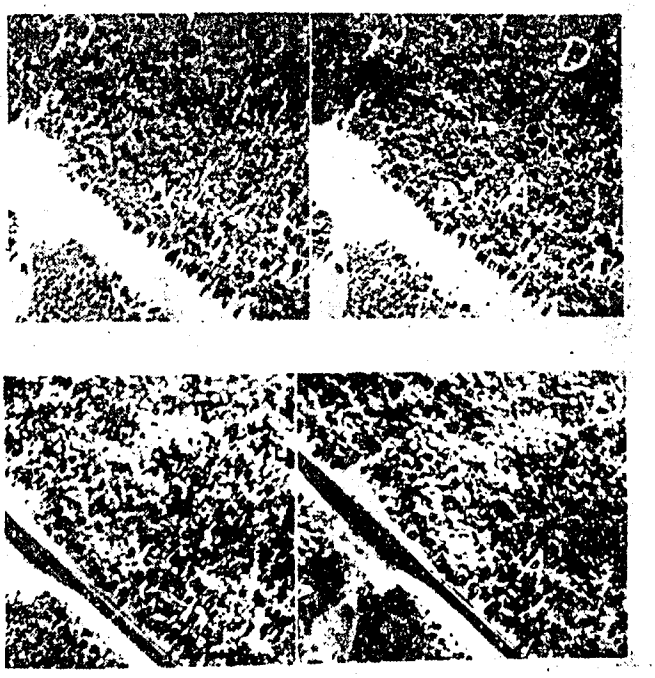


Fig. 17—*Panchromatic and infra-red photos of a forest area. These photos were taken with the same camera (12-inch focal length) at the same scale (1:5000) and exposed on the same day in June at about the same time of day.*
Note that species contrasts are more apparent in the infra-red (lower stereogram) than in panchromatic photo (upper stereogram).

Fig. 18—*Infra-red with minus blue filter (modified infra-red photo). The photo is intermediate in its characteristics between normal infra-red and panchromatic because tonal variations occurring in normal infra-red maintained but overall contrast is cut down. are Shadows are black, otherwise the photo has the general appearance of being panchromatic.*

Filter

Filter is a transparent material used in the optical path of a camera lens to absorb a certain portion of the spectrum and prevent its reaching the sensitized photographic film. The use of a filter is essential because small dust and moisture particles in the atmosphere scatter light rays thus preventing distant images from registering on the film. The scattering of light rays also destroys fine detail on the photographs. (The effect of haze increases with rising altitude.) Due to their short wave lengths, blue light rays are scattered to a much greater extent than green and red rays. The use of a proper filter (e.g., minus blue) reduces the effect of haze by absorbing the short rays and transmitting only the longer wave lengths to the film. Because haze-cutting filters remove part of the available light, longer film exposures are required. The ratio of the increased exposure to the normal exposure is known as the "filter factor." The particulars of filters ordinarily used for black-and-white photography are given in Table 2.

Table 2. Kodak Wratten Filters Commonly used for Panchromatic and Infra-red Films[1]

Wratten No.	Special designation	Filter color	Light absorbed	Filter factor[2]		Uses or effects
				Pan	*IR*	
3	Aero No. 1	Light yellow	Ultraviolet, violet, some blue	1.5	—	Panchromatic
12	Minus blue	Medium yellow	Ultraviolet, violet, most blue	2.0	1.5	Panchromatic and modified infra-red
15	G	Dark yellow	Ultraviolet, violet, all blue	2.0	1.5	Panchromatic and modified infra-red
25	A	Red	Ultraviolet, violet, blue, green	4	2	Infra-red with high contrast
89B		Dark red	Ultraviolet and most of visible spectrum	—	3	Infra-red with extreme contrast

Season

The choice of a suitable season for flying aerial photographs would depend upon many considerations. The most important ones are:

1. Use to which the photography would be put.
2. Film-filter combination.
3. Location of the area, i.e. northern or sourthern hemisphere.
4. Extent of the area to be photographed.
5. Other considerations such as long rainy season, expectation of early or late snowfall, etc.

In view of the numerous variables involved, it is difficult to specify any particular season or film-filter combination without having previous knowledge of all the influencing factors. Therefore, it is best to present a general picture of the importance of films and seasons under different circumstances.

1. Adapted from "Kodak Materials for Aerial Photography," Eastman Kodak Company, 4th ed., 1953.
2. Filter factors are suggestive only; actual factor depends on prevailing light and atmospheric conditions.

An initial consideration in choosing a suitable time of the year for aerial photography is the specific information required from the photographs. For topographic mapping, photographs are usually taken during that season of the year when deciduous vegetation is devoid of leaves and the ground is free of snow cover (if snowfall is experienced in the area). In northern latitudes, winter photography is limited by the low angle of elevation of the sun which results in long and dark shadows. Days are also short and flying time is therefore limited. At high altitude in West Pakistan, i.e., Kagan, Chitral, Upper Swat and Gilgit, winter photography is limited by bad weather in addition to snow and ice which tend to obscure essential detail.

In forestry work, dormant season photography is useful when data concerning evergreen species are desired or where it is intended to separate evergreen from deciduous areas. But generally weather conditions are unfavorable during winter and therefore summer photography is preferred.

Films, Filters and Season Combination

Aerial photography is generally accomplished by the following combinations:

1. Spring-pan-minus blue.
2. Summer-pan-minus blue.
3. Summer-infra-red-minus blue.
4. Summer-infra-red-red filter.
5. Autumn-pan-minus blue.
6. Winter-infra-red-minus blue.
7. Winter-pan-minus blue.

Spring-Pan-Minus Blue

During spring the newly developed leaves of deciduous trees are light yellow-green in contrast to the dark green leaves of the conifers. If photography is taken at this time with panchromatic film and minus blue filter, it will produce maximum differentiation in foliage colouration. Furthermore, during spring the sun is high in the sky thus reducing the amount of shade on the ground and consequently the amount of detail lost in the shade is also reduced. Moreover at this time of the year the growth of underbrush is much less advanced, thus simplifying the problem of determining the ground level. But this photography has certain limitations. The amount of time available is very short and the tone in which trees would photograph is not consistent for all species. This photography is, therefore, not suitable for mountainous region of West Pakistan.

Summer-Pan-Minus Blue

Summer days and season are quite long and weather conditions are generally good. Aerial photography is, therefore, carried out during summer months when the foliage is at normal colouration. This photography is particularly suitable for mountainous region of West Pakistan where conifers predominate or in tropical areas like East Pakistan where vegetation is of the uniformly broadleaved type. In both places it produces pictures of excellent appearance and image sharpness. The photos, however, lack tonal contrast because all crowns are depicted in uniformly greyish tone, hence this photography is not suitable for mixed conifers and broadleaved species.

Summer-Infra-red-Minus Blue

This photography is also known as modified infra-red (Figure 18). It presents a compromise between the panchromatic and normal infra-red summer photography. The photos show detail with good sharpness and with adequate contrast. The photography is, therefore, considered superior to panchromatic photography for forest and vegetation mapping at small and medium scale in areas having mixed type of vegetation. In general, the use of this type of photography is greatest where tonal variations between the tree species, particularly between conifers and broadleaved trees, are of critical importance.

Summer-Infra-red-Red Filter

This photography is known as normal infra-red. It produces excessive contrast and is, therefore, considered unsuitable. Many common and important features are somewhat obscured and the detail is lost in shadows and in the extreme contrasting tones.

Autumn-Pan-Minus Blue

In many localities, there is a period of autumn colouration just before the deciduous trees start shedding their leaves. If photography is taken during this period, it is likely to obtain suitable contrast between evergreens and deciduous trees. It is also possible to separate many individual species on photographs taken during this period of one to two weeks length. But the greatest limitation of this type of photography is the short period available for obtaining it. It is extremely difficult to photograph extensive areas at just the right stage of colouration.

Winter-Infra-red-Minus Blue

It is one of the characteristics of infra-red film that it registers shadow in black tone. During winter the shadows are long due to low sun angle. If the photography is taken with infra-red film, the shadows would be dark and dense. This is not desirable in photo-interpretation of vegetation for the reason that shadows obscure ground detail. The photography is, therefore, not suitable for forestry purposes.

Winter-Pan-Minus Blue

Panchromatic film with minus blue fitler is universally used for photography during the dormant season in flat country. This photography is particularly useful for making accurate height measurements of tree by the "shadow method" when the shadows are dark and long and the absence of foliage from broad-leaved species permit topographic features to be clearly seen.

In case of very large-scale photography, winter is the most desirable season because the resolution of detail is sufficient to justify photographing deciduous vegetation in the leafless state. Not only can the ground detail be studied under such conditions but also the boles of the leafless trees themselves can be evaluated and even measured. The photography is suitable for East Pakistan.

Time of the Photography

The time of the day is an important consideration in determining the quality of the resultant photographs. If the photos are taken during morning when the

sun is low, the shadows are long and much of the ground detail is obscured. If the photos are taken at noon when the sun is overhead, hot spots may develope on the photos because the sun rays while passing through the aircraft intersect the ground inside the area of photo coverage. At the very centre of the hot spot is a point of "no shadow" due to the direct return of the light rays to the lens with subsequent over-exposure and loss of detail. From this area much of the detail is lost and the photos are considered defective from a photo-interpretation point of view. It is therefore essential to take aerial photography at that time of the day when the sun angle is more than 30° but less than 60° above the horizon, i.e., between 10 to 11 a.m. and 2 to 3 p.m.

V

Preparation of Photographs for Stereo-viewing

Equipment

Before going into the detail of stereo-viewing, it is necessary to specify the equipment required for stereo-viewing and photo-interpretation. Individual interpreter will require the following equipment:

1. Lens stereoscope.
2. Parallax bar or parallax wedge.
3. Aerial photo scale.
4. Acreage grid.
5. Inking compass.
6. 12" ruler calibrated in mm and 0.1".
7. Teasing needle.
8. Masking tape.
9. Soft rubber eraser.
10. Tree crown density scale.
11. 4-H pencil.
12. Coloured pencils (red, blue and green).
13. Clipboard or tatum.
14. Cleansing tissue.
15. Drafting instruments.
16. Tracing table.

Besides the above equipment, the interpreter will require the aerial photos to work on for any specific job. The aerial photos are taken in such a manner that the adjacent prints overlap about 60 per cent of their width in the line of flight and about 30 per cent between flight strips. Before going into further detail, it is necessary to explain the following terms frequently used in aerial photography.

Overlap

The word stereo-viewing means looking at the same object on two different photos under the stereoscope. Therefore, the essential condition for stereo-vision would be that the same object should appear on two adjacent photos. For this purpose it is necessary to take aerial photography in such a manner that the adjacent photos overlap within flight lines and between adjacent flight lines. This prodecure is known as overlapping. Overlap is of two types:

a. *Endlap.* The variations in endlap (overlap in line of flight) are permissible from 55 per cent to 65 per cent with an overall average of 60 per cent. If the endlap is less than 55 per cent, the photos are ill-suited for stereo-viewing and if it is more than 65 per cent, the endlap is ex-

cessive which would mean greater number of photo-prints than are actually required. In other words excessive endlap is a waste of money and insufficient end-lap is a loss of stereo-vision.

b. *Sidelap.* Sidelap can vary from 15 per cent to 45 per cent with overall average of 30 per cent. Sidelap larger or smaller than these limits has similar effect on stereo vision as discussed under endlap.

Crab

Crab is the term applied to skewing of the photographs from the line of flight. This condition is caused by:

(a) Failure to orient the camera with respect to the track of the aircraft.

(b) Any turning of an aircraft which causes its longitudinal axis to vary from the track of the plane (Figure 19).

Crab is indicated in vertical photography by the sides of the photographs not being parallel to flight line or base line.

It is measured in degrees. Ordinarily, it should not affect more than 10 per cent of the width of the picture. Crab greater than the above limit will reduce the image area susceptible to effective stereoscopic-viewing.

Drift

Drift is a condition created when the aircraft taking the photographs is gradually blown off course by wind moving across the line of flight. In other words, drift is a horizontal displacement of an aircraft, under the action of the wind, from the path it would have followed in calm air. Sometimes the word drift is also used to indicate a special condition of crab wherein the camera still continues to make exposures oriented to the predetermined line of flight while the aircraft has drifted from that line (Figure 19).

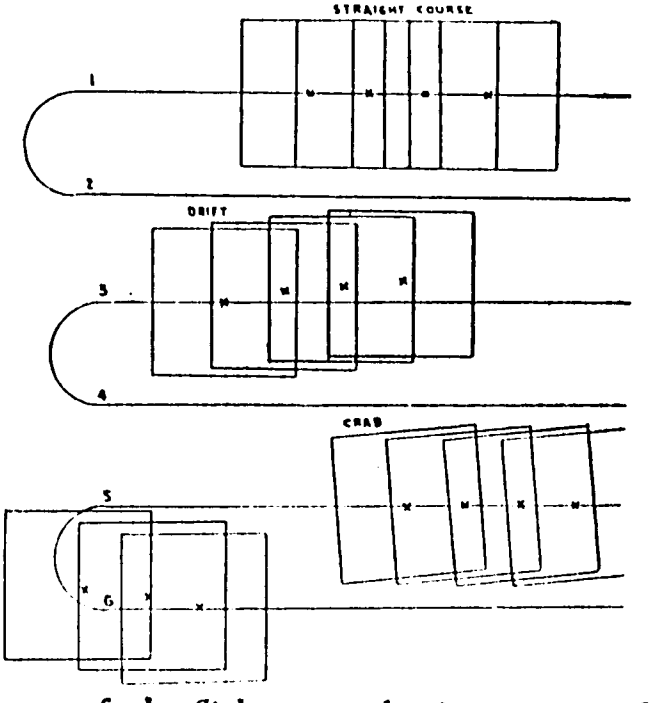


Fig. 19—*Diagram of the flight map showing spacing of photographs. (Note the crab and drift).*

Positioning of Photos for Stereo-vision

The following steps are systematically followed for orientation of the photographs for stereoscopic study.

1. The photographs are sorted pair-wise ranging from number one to the last photograph in the same flight line.
2. A stereo-pair is placed on the photo-interpretation table with shadows pointing toward the interpreter.
3. The principal point of each photograph is located by the intersection of lines drawn from opposite fiducial marks. The intersection is pin-pricked and labeled as PP.
4. The left hand photo is placed on the table and the right hand is placed over it in such a manner that the identical areas are superimposed. The photos are then separated in line of flight, until the conjugate images are somewhat less than the interpretor's interpupillary distance.
5. The stereoscope is now placed on the photos in such a manner that the lenses of the stereoscope are centred over conjugate points. At this stage, the interpreter would be able to see the objects in three dimensions under the stereoscope.
6. After the images are seen in three dimensions, the stereoscope is re-adjusted in such a manner that the principal point (PP) of the left photo is seen on the right hand photo in stereo. By using a teasing needle a pin-prick is made at that point on the right hand photo at which the principal point of the left hand photo is seen. This point is called as conjugate principal point (CPP).
7. The photos are kept in the same relative position but their places are changed. The left hand photo is now placed on the top of the right hand photo. They are once again readjusted and the position of principal point (PP) of the right hand photo is marked on the left hand photo (CPP) in the manner explained above.
8. The principal point and conjugate principal point on the same photo are joined together by means of a line which is designated as the "flight line" or "base line."
9. The left hand photo is now taped on the table. The right hand photo is placed over the left hand photo in such a manner that flight lines of both photographs make a straight line. The photos are now adjusted (pulled apart or brought closer) parallel to the line of flight until the principal point of left hand photo exactly coincides with the conjugate principal point of right hand photo in stereo. The right hand photo is now firmly secured to the table by means of masking tape.
10. The photos are now correctly oriented for stereoscopic study and for taking parallax measurements by means of a parallax wedge or a parallax bar.

VI

Image Displacement

Causes of Image Displacement

The difference between an accurate planimeteric map and a vertical aerial photograph lies in the fact that the former depicts all features at their correct horizontal position whereas the images on the latter are generally displaced from their true plane position because of : (i) Photographic deficiencies ; (ii) Ground relief ; (iii) and Tilt of the camera.

Displacement due to Photographic Deficiencies

Displacement due to photographic deficiencies can be caused by inferior lens, faulty assemblage of camera, faulty shutter, film shrinkage and the failure of the film-flattening mechanism at the camera focal plane. These deficiencies may result in a noticeable lack of sharpness in the images Distortion will also result if the whole picture is not exposed at one time. The aircraft may move a good many feet as the shutter slit travels forward resulting in displacements greater than 0.01 inch in medium scale photographs. The size of objects photographed is therefore distorted.

Serious distortion is produced by dimensional changes in the photographic materials. Aerial film is generally available on a low-shrink base, but gradual permanent shrinkage results, owing to loss of residual solvent and plasticizer from the base, plastic flow and release of mechanical strain. Moisture and temperature fluctuations produce temporary dimensional changes in film.

Displacement due to Ground Relief

Variations in ground relief is the most significant source of image displacement on vertical aerial photographs. The image of any feature lying above or below the horizontal ground surface (datum plane) would be displaced on a vertical aerial photograph from its true plan position. The direction of displacement is radial from the nadir (N) of the photograph. In a truly vertical photograph where nadir (N) coincides with principal point (PP) of the photograph, the following facts will hold good:

a. The topographic displacement varies directly with the height of the object and the distance between the object and the principal point (nadir).
b. Relief displacement is radial from the nadir and all objects of the same height and equidistance from the nadir in any direction will be displaced the same amount.
c. There is no displacement at nadir.
d. Objects projecting above a selected datum are displaced radially outward from the optical centre of the photo principal point (PP) on a

line passing through the true plane position of the object. (Figure 20).

e. Objects which are below a selected datum plane are displaced radially inward toward the centre of the photo on a straight line from their true plane position. (Figure 20).

f. Provided the scale remains the same, the degree of displacement increases as the focal length decreases (Figure 21).

g. Relief displacement varies inversely with the height of the photography. Greater will be the flying height lesser displacement:

h. Relief displacement varies directly with the height of the object. Taller objects are displaced more than shorter objects.

In conclusion it can be stated that relief displacement constitutes a source of error in measuring horizontal distances on aerial photographs because of displacement of the objects from their true plane position. It is this characteristic, however, that makes it possible to study overlapping prints stereoscopically. This point can be demonstrated by making two prints from the same negative, a three dimensional view on such prints is impossible to obtain due to a complete lack of relative image displacement. The purchaser of the aerial photography should, therefore, make certain that there is sufficient image displacement to ensure three-dimensional study, but at the same time try to avoid excessive displacement which prevents stereoscopic fusion.

Displacement due to Tilt

The tilt of the axis of the camera at the time of exposure causes marked displacement of images on the photograph but generally this displacement is less in magnitude than that produced by topographic relief. Figure 22 represents diagrammatically the displacing effect of tilt. From the diagram the following conclusions can be drawn:

1. Images on the upside of the tilted positives are displaced towards the centre of the photographs.

2. Images on the down side of the tilted positives are displaced away from the centre of the photographs.

3. In view of the validity of 1 and 2 above, large errors due to tilt in calculation of scales and distances from aerial photographs can be avoided by measuring the distance between two points which are:

(i) situated at the same elevation.

(ii) they are equidistant from the centre.

(iii) they are located diametrically opposite to the centre of the photograph.

In this way errors due to tilt will cancel out.

4. A circular area of 4.25 square inches in the centre of nearly vertical photograph may be considered free from tilt displacement for most purposes.

5. Images are normally displaced radially both from the photographic nadir as a result of relief and from iso-centre as a result of tilt.

6. Since tilt and topographic displacement are radial from different points, the combination of the two displacements in a single photograph will result in a lateral displacement of images.

A tilted photograph presents a slightly oblique view rather than a truly vertical record. Almost all aerial photographs are tilted to some degree because a perfectly vertical position can seldom be attained in a moving and vibrating aircraft. The focus of tilt displacement is referred to as the iso-centre which is defined as a point on the axis of tilt, lying approximately halfway between principal point (PP) and nadir (N) of the photograph.

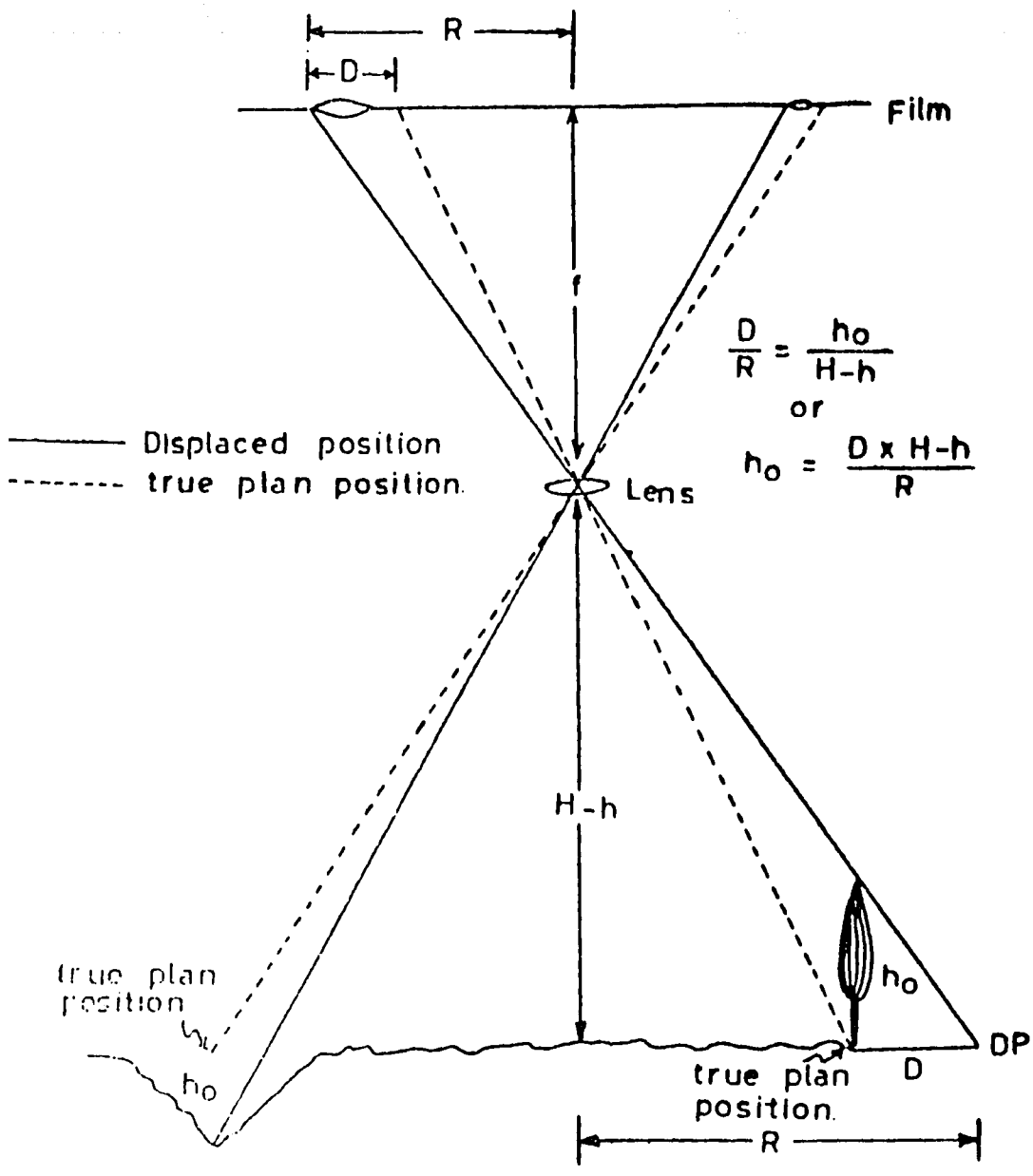


Fig. 20—*Displacement in single aerial photograph due to elevation.*

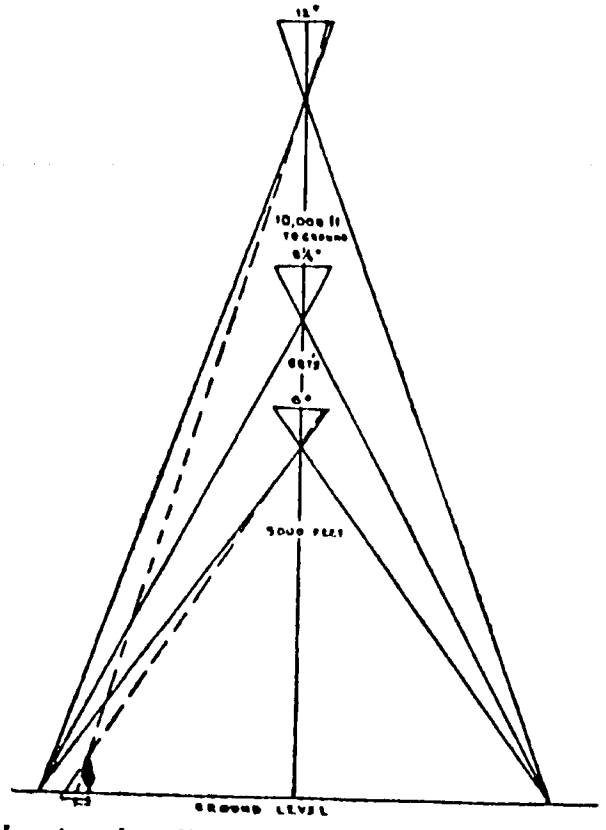


Fig. 21—*Diagram showing the effect of camera focal length on image displacement.*

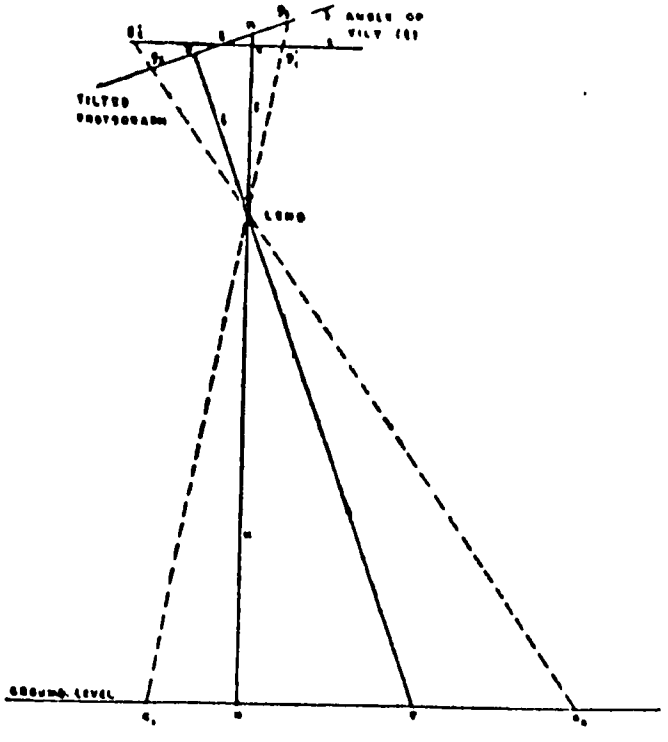


Fig. 22—*Diagram showing image displacement on single aerial photograph due to tilt.*

VII

Stereoscopic Parallax

Parallax

If a nearby object is observed alternately with the left and right eye, its location will appear to shift from one position to another. This apparent shift caused by a change in the place of observation is known as parallax. In other words parallax is an apparent displacement of an object when seen from two different points. In case of aerial photographs an object is viewed or photographed from two different positions. Consequently, an apparent shift in the position of that object takes place, which is referred to as parallactic displacement. On overlapping prints this displacement can be measured as a linear distance which is related to the height of the object. Figure 23 illustrates stereoscopic parallax in the case of two overlapping vertical aerial photographs.

Types of Parallax

Parallax is of two types:

1. Absolute parallax (X-parallax).
2. Y-parallax.

Absolute Parallax

Absolute parallax is defined as displacement along or parallel to the line of flight and is represented by the algebraic difference of the distances of corresponding images from their respective nadirs when measured parallel to the line of flight. For the sake of convenience and ease of measurements, the average photo base length of a stereo pair is commonly substituted for absolute stereoscopic parallax (P) in the solution of parallax equation. The results are reasonably accurate provided:

1. Tilt is less than (3°) three degrees.
2. Both nadir (N) and principal point (PP) are at the same ground elevation.
3. Both negatives are exposed from the same flight altitude.
4. Base of the object and principal point are approximately at the same ground level.

Y-parallax

Y-parallax is defined as displacement at right angles to the line of flight. Since Y-parallax is not commonly used in aerial photography for forestry purposes, no further explanation of Y-parallax is given here.

Parallax Difference

The difference in absolute stereoscopic parallax between two different image points is a measure of the distance of one point above the other. In other words,

parallax difference (dP) is a difference between the absolute parallax at the top and absolute parallax at the bottom of an object.

Parallax Formula

The basic parallax formula is derived from an analysis of the geometry of the stereoscopic pair as illustrated in Figure 22. From the diagram the following relationship can be established.

$$\frac{h_o}{H-h} = \frac{d+d}{(x+x')+(d+d)'} \quad \text{or}$$

$$\frac{h_o}{H-h} = \frac{dP}{P+dP} \quad \text{or}$$

$$h_o = \frac{(H-h)(dP)}{P+dP}$$

where : h_o = height of object.
P = absolute parallax at the base of object.
dP = parallax difference.
H = height of camera above sea level.
h = height of datum plane above sea level.

Explanation

Consider a pair of truly vertical aerial photographs taken from the same flying height, the parallax (P) is equal to the algebraic difference of the distances of the two images from their respective principal points parallel to the line of flight (Figure 23). In other words:

$$P = x-(-x') = x+x'$$

Therefore, when two principal points are at the same elevation, and the photos are free from tilt and scale differences, the parallax (P) of a point on the ground will equal to the distance between principal point and conjugate principal point of a stereo-pair.

In Figure 24, the absolute parallax (P) of the bottom of the flag pole is:

$$P = AS+VB$$

The absolute parallax of the top of the flagpole is:

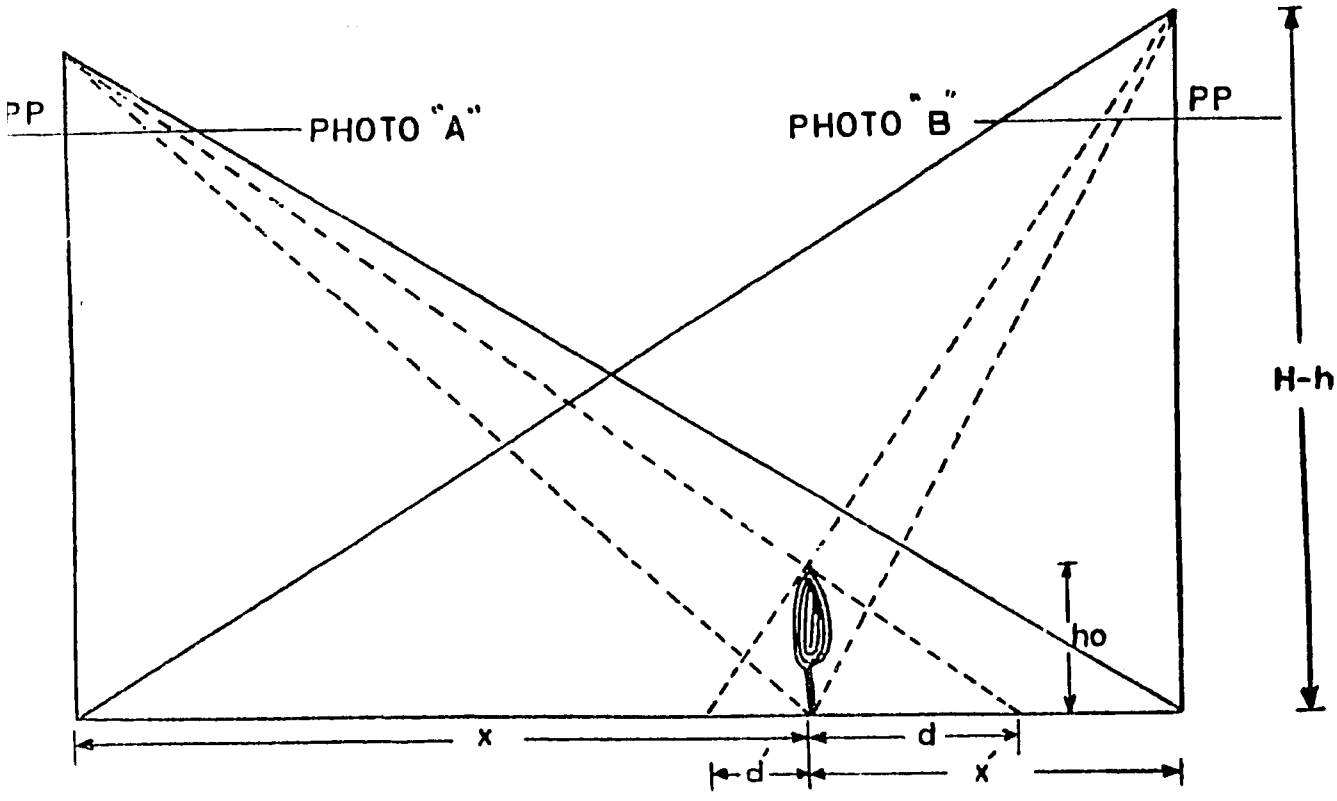
$$P+dP = At+UB$$

The difference between the absolute parallax of the top of the pole and the absolute parallax of the bottom of the pole is:

$$(P+dP-P) = At+UB-AS+VB \quad \text{or}$$

$$dP = St+UV$$

In other words, the parallax difference is equal to the sum of the displacements of the pole image parallel to the line of flight. The validity of the above explanation is subject to the fulfilment of the four conditions necessary for the convenent measurement of absolute parallax.



$$\frac{ho}{H-h} = \frac{d+d'}{(x+x')+(d+d')} \quad \text{OR} \quad \frac{ho}{H-h} = \frac{dP}{P+dP} \quad \text{OR} \quad ho = \frac{H-h}{P+dF}$$

Fig. 23—*Diagram showing derivation of the parallax equation.*

Applications of the Parallax Formula

The parallax formula has the following applications in forestry and aerial surveying:

1. The theory of parallax differences is considered as a key to the construction of maps from aerial photographs. But since aerial photographs have various displacements, some sort of control is necessary for accurate mapping. This control is ordinarily established by means of radial line triangulation and the detail is transferred by techniques designed to eliminate or reduce errors on the map due to displacement in the photographs.
2. Parallax makes stereoscopic vision possible. Furthermore, it can be measured and utilized in the measurement of trees' height, and ground slopes. The details of these operations will be discussed later.

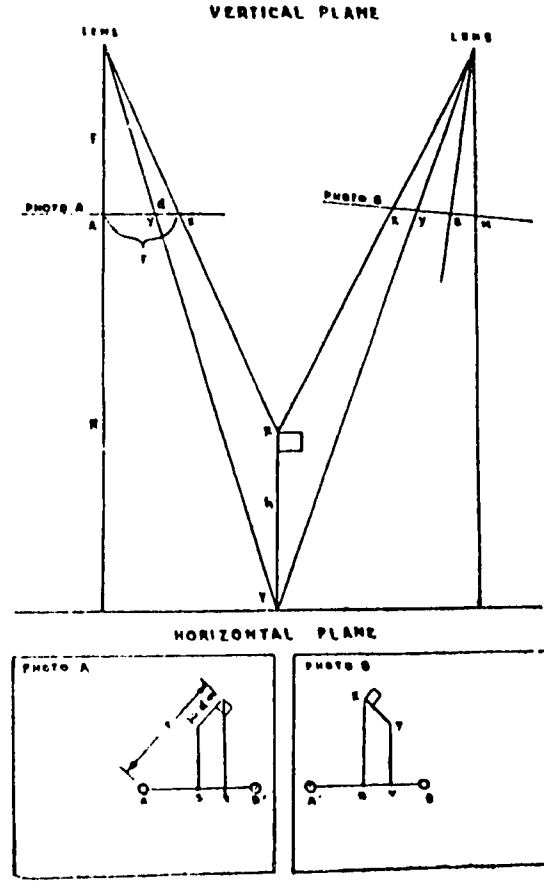


Fig. 24—*Diagram showing the geometric relationship of the stereo-pair.*

VIII

Photo-scale Measurements

Scale

Scale is defined as a ratio between photo distance and ground distance. It is generally expressed in terms of the "Representative Fraction" (RF) which is also called "natural scale ratio." If a photograph is said to have an R. F. of 1:10,000, it simply means that a given distance on the ground is 10,000 times greater than on the photograph. Since natural scale is just a ratio, it is independent of units of measurement.

The natural scale can be readily converted to feet per inch, chains per inch or inches per mile by use of the proper conversion factors. The scale after conversion is known as verbal scale (4"=1 mile). A photograph with an RF of 1:15,840 has a verbal scale of 1"=1320' or 1"=20 chains or 4"=1 mile. Conversion from representative fractions to other common units of measurements are given in Table 3.

Conversions for scales not shown can be made from the relationships listed at the bottom of each column. Using the scale of 1:7,920 as an example (col. 1, line 1), the number of feet per inch is computed by dividing the representative fraction denominator (RFD) by 12 (no. of inches per foot). Thus, 7,920/12 =660 feet per inch (col. 2). By dividing the RFD by 792 (inches per chain), the number of chains per inch is derived (col. 3). Other calculations can be made similarly. Under colum 4, the figure 63,360 represents the number of inches in one mile; in column 5, the figure 6,272,640 is the number of square inches in one acre; and in column 6, the number 640 is acres per square mile.

Table 3. Scale Conversion for Vertical Aerial Photographs

R. F	Feet per inch	Chains per inch	Inches per mile	Acres per square inch	Square mile per square inch
1: 7,920	660.00	10.00	8.00	10.00	0.0156
1: 8,000	666.67	10.10	7.92	10.20	0.0159
1: 8,400	700.00	10.61	7.54	11.25	0.0176
1: 9,000	750.00	11.36	7.04	12.91	0.0202
1: 9,600	800.00	12.12	6.60	14.69	0.0230
1: 10,000	833.33	12.63	6.34	15.94	0.0249
1: 10,800	900.00	13.64	5.87	18.60	0.0291
1: 12,000	1,000.00	15.15	5.28	22.96	0.0359
1: 13,200	1,100.00	16.67	4.80	27.78	0.0434
1: 14,400	1,200.00	18.18	4.40	33.06	0.0517

R. F.	Feet per inch	Chains per inch	Inches per mile	Acres per square inch	Square mile per square inch
1: 15,000	1,250.00	18.94	4.22	35.87	0.0560
1: 15,600	1,300.00	19.70	4.06	38.80	0.0606
1: 15,840	1,320.00	20.00	4.00	40.00	0.0625
1: 16,000	1,333.33	20.20	3.96	40.81	0.0638
1: 16,800	1,400.00	21.21	3.77	45.00	0.0703
1: 18,000	1,500.00	22.73	3.52	51.65	0.0807
1: 19,200	1,600.00	24.24	3.30	58.77	0.0918
1: 20,000	1,666.67	25.25	3.17	63.77	0.0996
1: 20,400	1,700.00	25.76	3.11	66.34	0.1037
1: 21,120	1,760.00	26.67	3.00	71.11	0.1111
1: 21,600	1,800.00	27.27	2.93	74.38	0.1162
1: 22,800	1,900.00	28.79	2.78	82.87	0.1295
1: 24,000	2,000.00	30.30	2.64	91.83	0.1435
1: 25,000	2,083.33	31.57	2.53	99.64	0.1557
1: 31,680	2,640.00	40.00	2.00	160.00	0.2500
Method of Calculation	$\frac{RFD}{12}$	$\frac{RFD}{792}$	$\frac{63,360}{RFD}$	$\frac{(RFD)^2}{6,272,640}$	$\frac{Acres/sq.in}{640}$

Calculation of Scale

Representative fraction (RF) of aerial photographs can be determined from focal length (f) of the camera and the flying height (H) of the aircraft above ground level by means of the following relationship:

$$R.F. = \frac{\text{Focal Length in Feet (f)}}{\text{Flying Height Above Ground in Feet (H)}}$$

The diagram in Figure 22 illustrates the relationship between the flying height, focal length, and scale by comparison of similar triangles where f and H are expressed in feet or in the same units of measure. For example, if a photograph was taken by a camera having focal length of 6 inches from a plane flying 8,000 feet above ground, the scale would be:

$$R.F. = \frac{f}{H} = \frac{0.5}{8,000} = 1:16,000$$

Scale can also be calculated without reference to focal length or flying height if the photographic and ground distances are known (Figure 25). For example, if the distance between two points on a photograph is 3 inches (0.25') and the distance between the same points is measured on the ground or from a map of known scale and is found to be 4,000 feet, the scale would be calculated as follows:

$$R.F. = \frac{\text{Photo Distance in Feet}}{\text{Ground Distance in Feet}} = \frac{0.25}{4,000} = 1:16,000$$

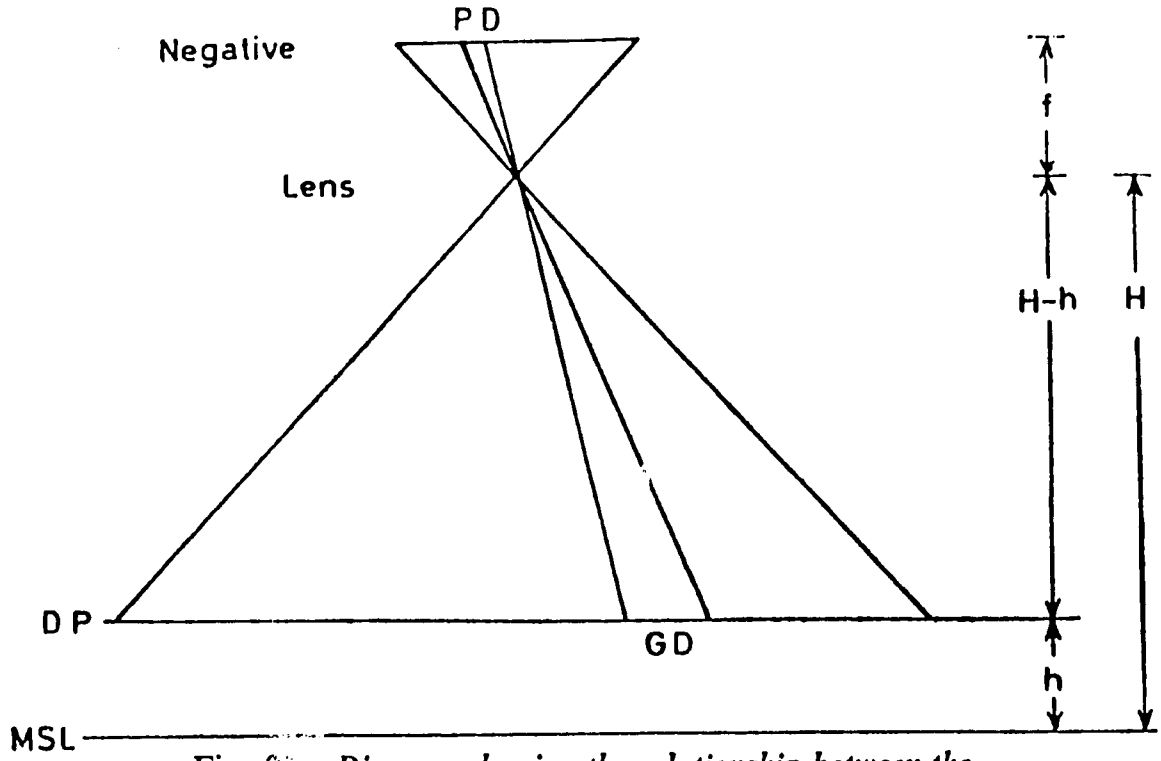


Fig. 25—*Diagram showing the relationship between the flying height, focal length and photo scale.*

Once the distance between two points on a photograph has been determined, the flying height above the average elevation of these two points can be readily calculated from the above formula. For instance, if it is known that a photograph is at a scale of 1:12,000 and that 8.25 inches focal length lens was used, then flying height (H) can be calculated as:

$$\frac{1}{12{,}000} = \frac{8.25}{12 \times H}$$

$$H = \frac{8.25 \times 12{,}000}{12} = 8{,}250 \text{ feet}$$

Similarly if the scale and the flying height are known, focal length (f) of the lens can be calculated as:

$$\frac{1}{12{,}000} = \frac{f}{8{,}250}$$

$$f = \frac{8{,}250}{12{,}000} = 8.25 \text{ inches}$$

Variations in Scale

If the ground was always perfectly level and if the cameras were always pointed absolutely vertical, the scale of the photograph would be constant and easy to determine. Unfortunately, these two conditions are seldom fulfilled. The greatest cause of scale variation in photographs is caused by varying ground elevation. From the formula given above, it can be seen that scale varies proportionately to the height of the aircraft above the ground. Whenever the ground varies in elevation, the flying height will vary too (Figure 26). Consequently, a given photograph will have as many scales as there are ground elevations in the area photographed (Figure 27). For example, if a 12-inch focal length camera in an aircraft flying 10,000 feet above sea level is used to take photographs of ground varying in elevation from sea level to 2,000 feet, the nominal scale of the photograph would be computed from the mean elevation of the ground. Thus if the plane is flying at 10,000 feet above sea level (H) and the height of datum line (average ground elevation) (h) is 500 feet, the photograph would be said to have a scale of 1:9500 and would be calculated by the modified form of the above formula:

$$\text{R.F.} = \frac{f}{H - h} = \frac{12/12}{(10{,}000 - 500)} = \frac{1}{9500} = 1:9500$$

The second cause of variation in photographic scale is caused by the tilt of the axis of the camera at the moment of photography. The more obliquely the ground is viewed, the farther will be the distance from the camera to the ground photographed and the smaller will be the scale. In nearly vertical photographs, the error in scale introduced by tilt is not large and may be disregarded for all practical purposes. Because of the possibility of tilt, it is advisable in measuring the distance between two points on the photograph, to pick two points which are diametrically opposite and equidistant from the centre of the photograph. This will minimize the error due to tilt.

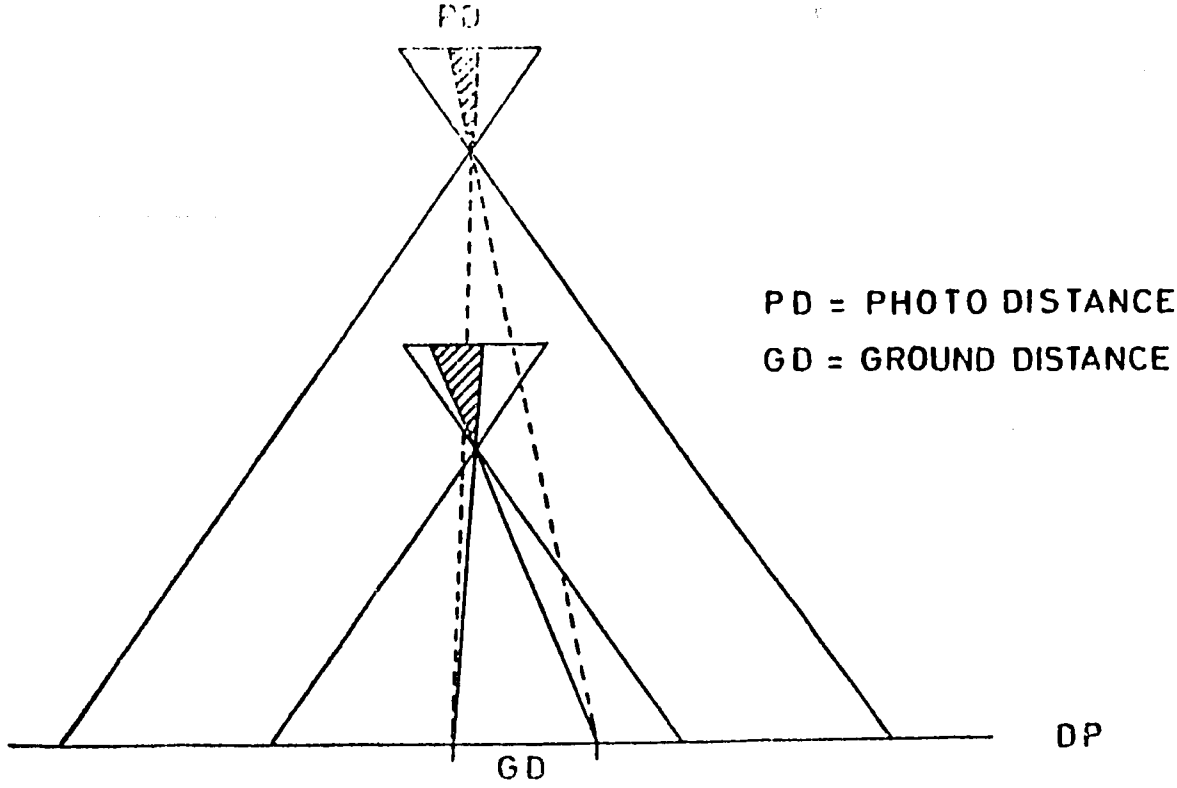


Fig. 26—*Diagram showing the relationship between photo distance and ground distance.*

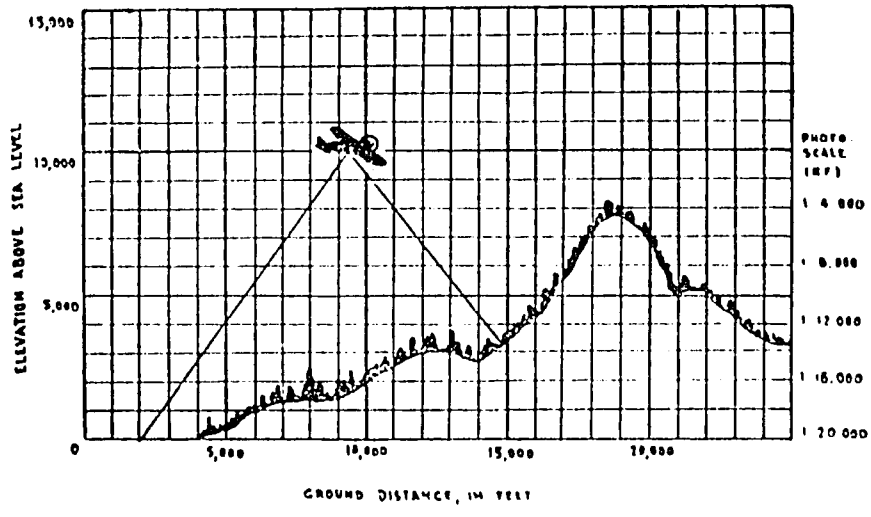


Fig. 27--*Diagram showing the effect of ground elevation on photo scale. A six inch focal length camera is assumed here.*

Common Scale Ranges

The photographs of the following scales are generally used for various purposes in forestry and other allied fields.

Scale	*Utility*
1:40,000 to 1:50,000	Small scale mapping and preliminary reconnaissance.
1:30,000 to 1:31,680	Medium to small scale mapping and reconnaissance.
1:24,000 to 1:25,000	Medium scale mapping, minimum scale for reasonably detailed photo-interpretation for forestry, soil geology and urban studies.
1:20,000	Widely used for agricultural survey in U.S.A.; considered satisfactory for a wide range of photo-interpretation purposes where a high degree of precision is not required.
1:15,000 to 1:15,840	Widely used for detailed photo-interpretation in forestry, soils, and geology.
1:10,000 to 1:9,600	Large scale mapping, detailed geological and forestry photo-interpretation, city planning, highway location and hydro-electric projects.
1:5,000 to 1:4,800	Largest practical aerial photography with conventional equipment, used for engineering plans, mining property maps, detailed mapping and photo-interpretation of high value areas such as cities, industrial installations and highway intersections and strip samples of forests.

Choice of Focal Length

Figure 28 illustrates the effect of comera focal length on photo scale.

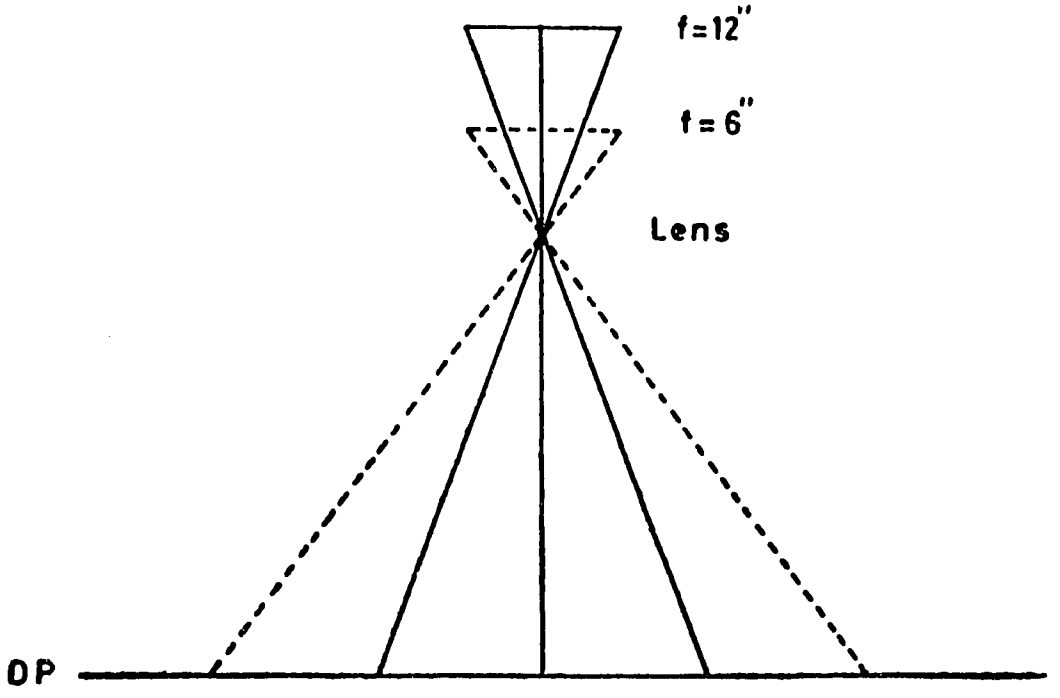


Fig. 28—*Diagram showing the effect of camera focal length on photo scale.*

Aerial cameras taking 9-inch square negatives are generally equipped with 6-inch, 8.25-inch and 12-inch lenses. Other focal lengths are available for special purposes. If the 12-inch lens is used at 5,000 feet elevation, the scale of resultant photography will be 1:5000. At the other extreme, if the 6-inch lens is used at 16,000 feet, the resultant scale will be 1:32,000. Between these scales lies the range of scales of most commercial photography.

A great deal of the aerial photography for commercial uses are taken with an 8.25-inch focal length lens. For smaller scales the 6-inch focal length lenses are frequently used. For larger scales, the 12-inch focal length lens is preferred. For a given scale, since a shorter focal length requires flying at a lower altitude, the effect of using a short focal length lens is to increase topographic displacement, distortion and the apparent depth of the third dimension in the stereoscopic image. Increased displacement is desirable in the photography of relatively flat country, but is highly undesirable in the photography of rough terrain. The 6-inch lens therefore, is generally specified in photography of relatively flat terrain and the 12-inch lens in photography of very hilly or mountainous country. Over country of moderate relief or where doubt exists about the choice, the 8.25-inch camera is generally used.

IX

Height Measurements

Tree height can be measured on aerial photographs by making use of the following photo-image charactristics:

1. Radial displacement.
2. Parallax.
3. Shadow lengths.

Radial Displacement Method

Radial displacement of tall objects, like trees, pictured near the edges of the large-scale vertical photographs can be utilized for fairly accurate measurement of tree height on a single photograph. As already discussed in Chapter VI the degree of displacement is directly proportional to the height of the object and its distance from nadir. Since the top of the tree in a photograph is at a higher elevation than the ground or stump level, the top will be displaced outward from the centre of the photograph. Now if the displacement (D) of the tree-image on the aerial photograph is measured and the radial distance (R) from nadir to the top of the displaced image is known, the height of the tree or any other tall object can be calculated from the following simple relationship (Figure 20)

$$ho = \frac{D \times H}{R}$$

Where: ho= height of the object in feet.

H= height of the plane above the base of the object in feet.

D= length of the displaced image on the photograph in inches.

R= radial distance from the nadir to the top of the displaced image in inches.

The above relationship will hold true provided the following conditions are fulfilled:

(i) When the photograph has less than 2 per cent tilt so that principal point can be accepted as the nadir position.

(ii) When the flight altitude above the base of the object can be precisely determined.

(iii) When the top and the base of the object are clearly visible on the aerial photograph.

(iv) When the degree of image displacement is large enough to permit accurate measurement.

For the purpose of illustrating the above procedure, the following examples are given.

Example 1

Figure 29 indicates displaced images of four objects. They are:

a = Square chimney with a radial displacement (D) = 0.70″ and radial distance (R) = 4.25″ measured on photo.

b = Pyramid with a radial displacement (D) = 0.86″ and radial distance (R) = 1.84″.

c = Cone with a radial displacement (D) = 0.69″ and radial distance (R) = 3.42″.

d = Building with a radio tower and a flagpole on the top of it. Radial displacement (D) of building = 1.31″, radio tower = 0.44″, and flagpole = 0.33″ and the radial distance (R) is 4.44″, 4.89″ and 5.22″ respectively.

The scale of the photography (RF) is 1:1500. The focal length (f) of the camera is equal to 6 inches, and the height of the aircraft above mean ground elevation (H-h) is equal to 750 feet. On the basis of the diagrams given in figure and the information presented above,. the heights (h) of the square chimney, pyramid, cone, building, radio tower and flagpole are calculated as follows:

1. The (height) of the square chimney

$$h_o = \frac{D \times (H-h)}{R} = \frac{0.7 \times 750}{4.25} = 123.5 \text{ or say 123 feet.}$$

2. The (height) of the pyramid

$$h_o = \frac{D \times (H-h)}{R} = \frac{0.86 \times 750}{1.84} = 350.5 \text{ or say 350 feet,}$$

3. The (height) of the cone

$$h_o = \frac{D \times (H-h)}{R} = \frac{0.69 \times 750}{3.42} = 151.4 \text{ or say 151 feet.}$$

4. The combined height of the building, radio tower and flagpole.

$$h_o = \frac{D \times (H-h)}{R} = \frac{2.08 \times 750}{5.22} = 299 \text{ feet.}$$

5. Height of building

$$h_o = \frac{D \times (H-h)}{R} = \frac{1.31 \times 750}{4.44} = 221.3 \text{ or say 221 feet.}$$

6. Height of radio tower

$$h_o = \frac{D \times H-h}{R} = \frac{0.44 \times 750}{4.89} = 67.5 \text{ or say 68 feet.}$$

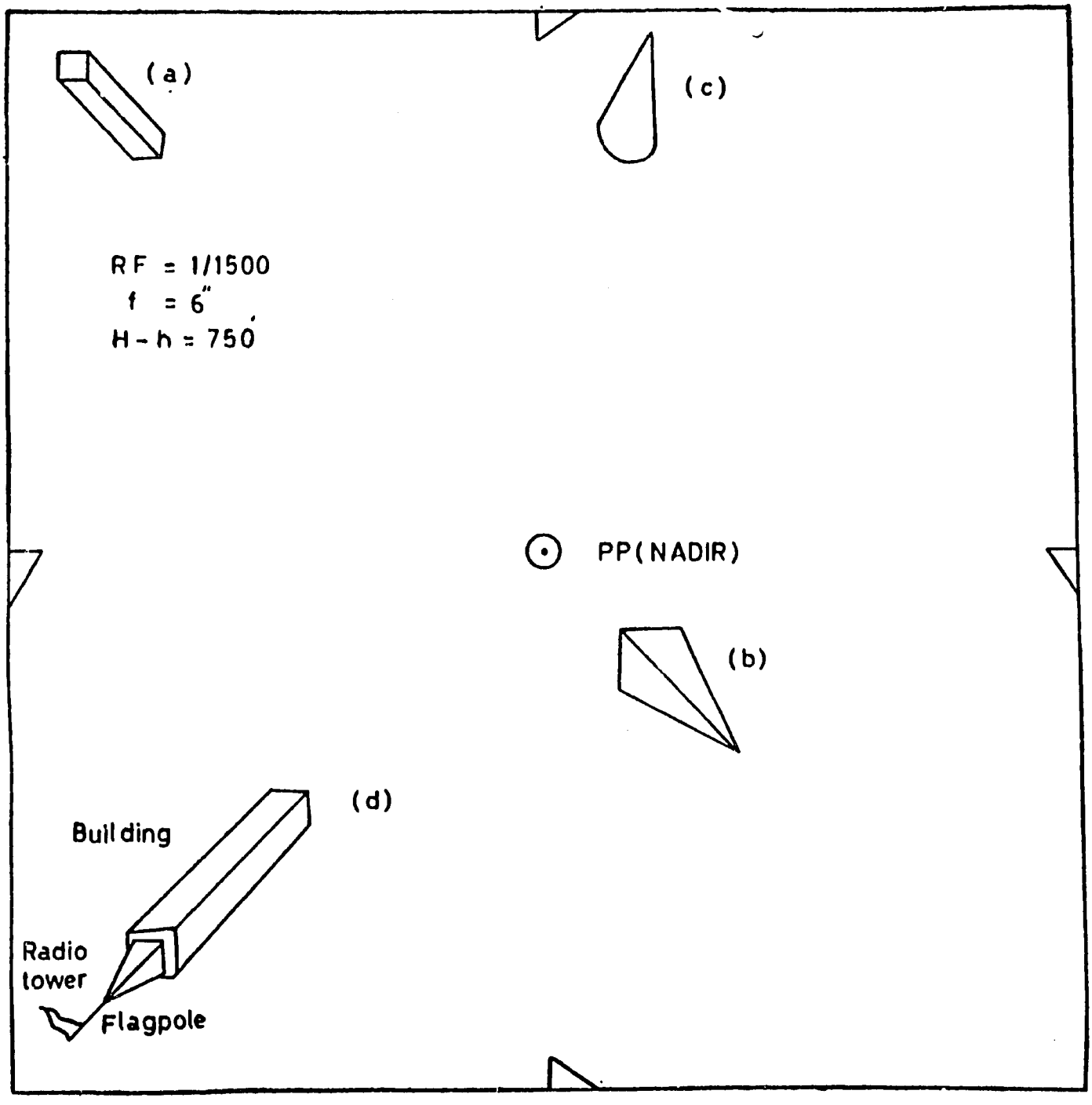


Fig. 29—*Diagram showing the amount of image displacement on single aerial photograph (an hypothetical example).*

7. Height of flagpole

$$h_o = \frac{D \times H - h}{R} = \frac{0.33 \times 750}{5.22} = 47.4 \text{ or say } 47 \text{ feet.}$$

Example 2

Figure 30 shows an aerial photograph of Badshahi mosque taken from a flying height of 1,500 feet above ground level with a camera of focal length 6 inches. The radial displacements of the minaretes at A and B are measured to be 0.20 inch and 0.26 inch respectively. The radial distance of the minaretes A from nadir (PP) is 1.99 inches and B is 2.65 inches. The height of A and B can be calculated by the following formula :

$$h_o = \frac{D \times H}{R}$$

Substituting the value for A we get

$$h_o = \frac{0.20 \times 1,500}{1.99} = 150 \text{ feet}$$

Substituting the value for B, we get

$$h_o = \frac{0.26 \times 1500}{2.65} = 147 \text{ feet}$$

The actual height of each minaret of Badshahi mosque is 143 feet 6 inches.

Parallax Method

The theory of this method is based upon the difference in parallax readings at the base and top of the tall objects like trees, towers, smoke stacks, etc. Parallax readings are taken at the base and top of the object whose height is required to be determined with the help of parallax measuring instruments such as a parallax wedge or parallax bar. These measurements are taken by looking at the stereo-pair under a stereoscope. The difference between the two readings is converted into the height of the object by means of parallax formula discussed in Chapter VII. The procedure is explained below.

A stereo-pair showing the object whose height is required to be measured is properly orientated and tapped to the table for stereovision. Figure 31 shows the Washington Monument in a stereo-pair ready for parallax measurement. The parallax between the top and bottom is measured, which in this case is 1.46 inches and 2.06 inches respectively. From these two readings, parallax difference (dP) is determined (0.60 inches in this case). The scale of the photograph at the base of the Monument has been found to be 1:4,600. Since a 12-inch focal length camera was used for taking the photograph, the height of the aircraft above ground level would also be 4,600 feet. The average photo base length (P) for the stereo-pair is 4.40 inches. Substituting these values in the parallax formula, we get;

$$h_o = \frac{(H-h)\,dP}{P+dP} = \frac{4,600 \times 0.60}{4.40 \times 0.60} = \frac{2760}{5} = 552 \text{ feet}$$

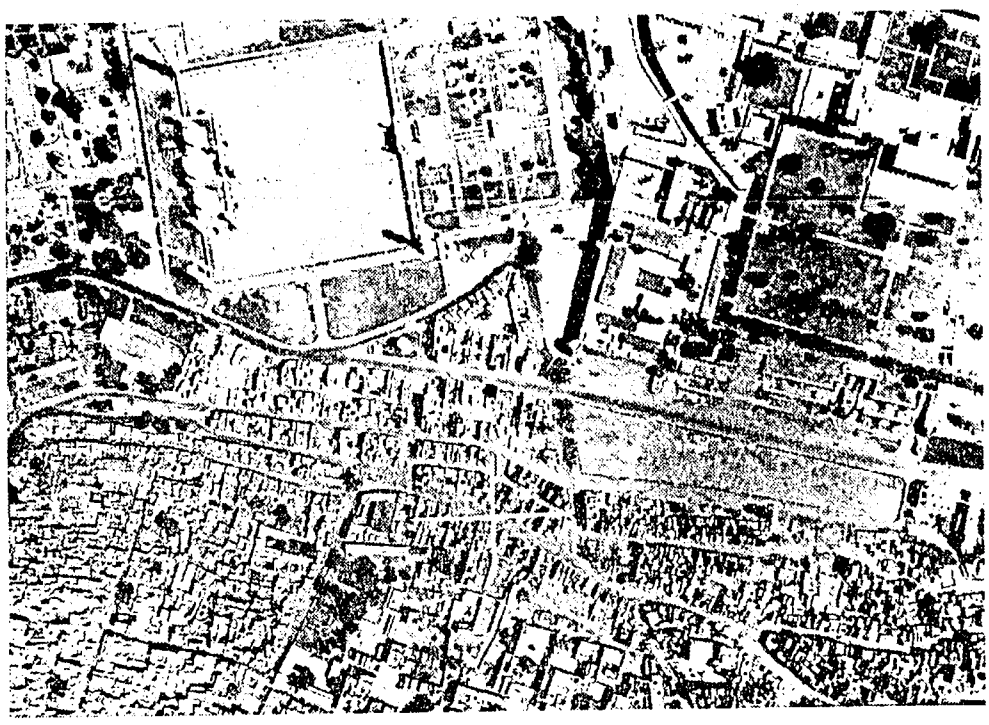


Fig. 30—*Photograph of Badshahi Mosque, Lahore showing the amount of image displacement in "A" and "B" which are of exactly the same height. The object marked as B shows more image displacement because it is farther from the nadir. This characteristic is taken advantage of in calculating the height of tall objects.*

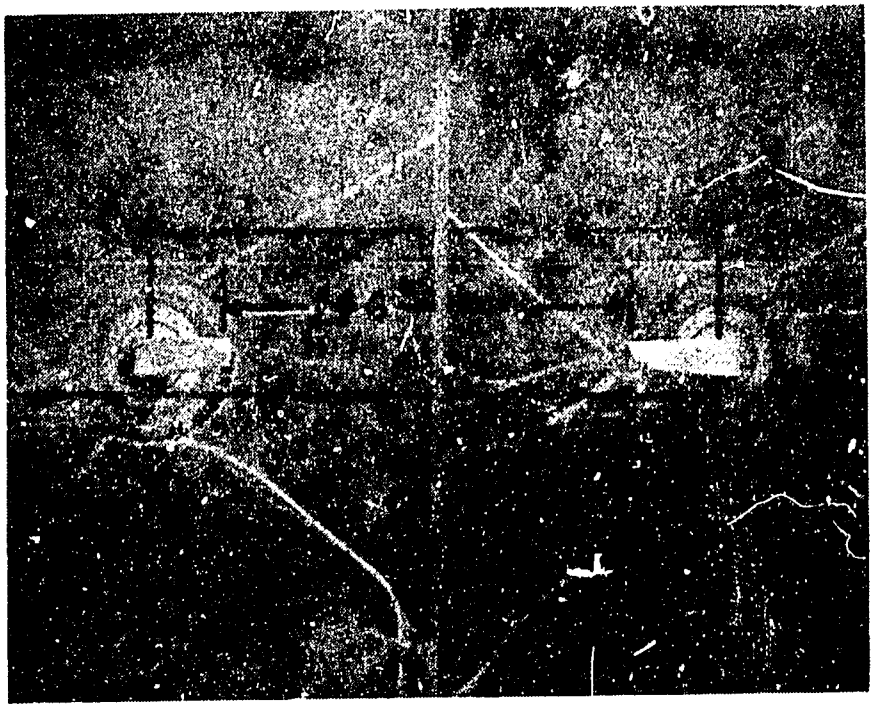


Fig. 31—*Stereogram showing parallax (P) of the top and bottom of Washington Monument.*

The exact height of the Washington Monument is 555 feet and 5 inches. Thus, there is a difference of approximately 3 feet which is within a reasonable limit of accuracy.

As mentioned in Chapter VII and also in the preceding paragraph, the average photo base length of a stereo-pair is commonly substituted for stereoscopic parallax (P) in the solution of the parallax equation. This procedure produces reasonably accurate results provided:

(i) Photographic tilt is less than 3 degrees.
(ii) Both negatives of the stereo-pair are exposed from the same flight altitude.
(iii) Principal points of both the photos are at the same ground elevation.
(iv) The base of the object to be measured is at the same elevation as the principal point.

The parallax method of height measurement is much more accurate and reliable than the radial displacement method or the shadow method. With the parallax method, the height of most trees growing adjacent to open ground can be determined on a high quality medium scale photography (e.g. 1:15840) with a standard error of approximately 5 feet. He has further reported that when the heights of a number of trees are averaged, mean parallax measurements made on the aerial photograph frequently differ by less than one foot from mean height measurements made on the ground.

The chief disadvantage of parallax method lies in the fact that it requires more training and much more experience than is required for any other method. Moreover, the accuracy of height measurement would depend upon the observance of the following precautions:

(i) In rough terrain, the calculation of photo scale and flying height for each overlap is necessary. Similarly for stands located on ridges or in valleys below the datum plane, it is more desirable to calculate new values for absolute stereoscopic parallax than to use the average photo base length.
(ii) Once a pair of photographs has been aligned for stereo-viewing, they should be fastened down to avoid movement. A slip of either photograph between the parallax reading at the base and the top of a tree may yield inaccurate readings.
(iii) To avoid single measurement of high variability, it is advisable to take several readings of the same tree or stand and average the readings both for the top and for the base of the object.

Shadow Method

The relationship between tree height and shadow length was first established as follows:

$$h_o = L \times \frac{1}{RF} \tan \theta$$

Where: h_o = height of the tree.
L = length of shadow on the aerial photograph.
RF = Representative Fraction (scale of photograph).
θ = angle of elevation of the sun.

The scale of the photograph and measurement of the shadow lengths are easy to accomplish but the determination of the tangent of angle θ would require

further explanation. If the angular elevation of the sun is known or can be determined at the time and place of the photograph, it would be easyt o determine the tree height from the shadow length by using the tangent of the sun elevation, taking into account the difference in scale between the shadow image on the photograph and the actual tree. In Figure 31 the angle θ is the angular elevation of the sun at a given time, latitude and longitude. Since each photograph is taken at a different time and with different sun angles, the value of tangent θ will vary from photograph to photograph.

Example

If the length of the shadow measured on the photograph is equal to 2.8 millimeters, the scale of photography is 1:15,000 and the angle θ is equal to 36°; the height of the object casting this shadow can be determined by the following formula:

$$h_o = R \cdot \frac{1}{R.F.} \cdot \tan \theta$$

The value of tan θ is obtained from a table or curve prepared for this purpose. In the present case, the value of tan 36° is equal to 0.7265. The value of 2.8 mm is expressed in metres to get the height of the object in metres. Now by substituting the above values in the formula we get:

$$h_o = 0.0028 \times 15{,}000 \times 0.7265 = 30.5 \text{ metres.}$$

Therefore, the height of the object is 30.5 metres or approximately 100 feet. Although this method is successfully used in many countries, particularly Canada, for measuring the height of trees, the fact is that this method suffers from numerous limitations, some of which are explained below:

(i) The method can be accurately used provided the shadows are long and sharp so that they can be correctly measured.

(ii) The object has to be located in an isolated place on level ground so that the shadow is unobstructed and free from slope effect.

(iii) The time of exposure and the approximate geographic position of the locality must be known for the calculation of the inclination of the sun. In many situations it would be difficult to keep track of all these influencing factors to the extent of the precision required.

(iv) The method is unsuitable for dense and fully stocked forests because in such situations the shadows are rarely clear and adequate.

(v) Difficulty is experienced in measuring the shadow lengths of broadleaved species which have generally irregular crown shape. Usefulness of this method is therefore limited for broadleaved species.

In view of the above limitations, this method is seldom used in the United States particularly for a scale smaller than 1:10,000. So far as tropical and subtropical countries are concerned, this method offers little or no promise for use.

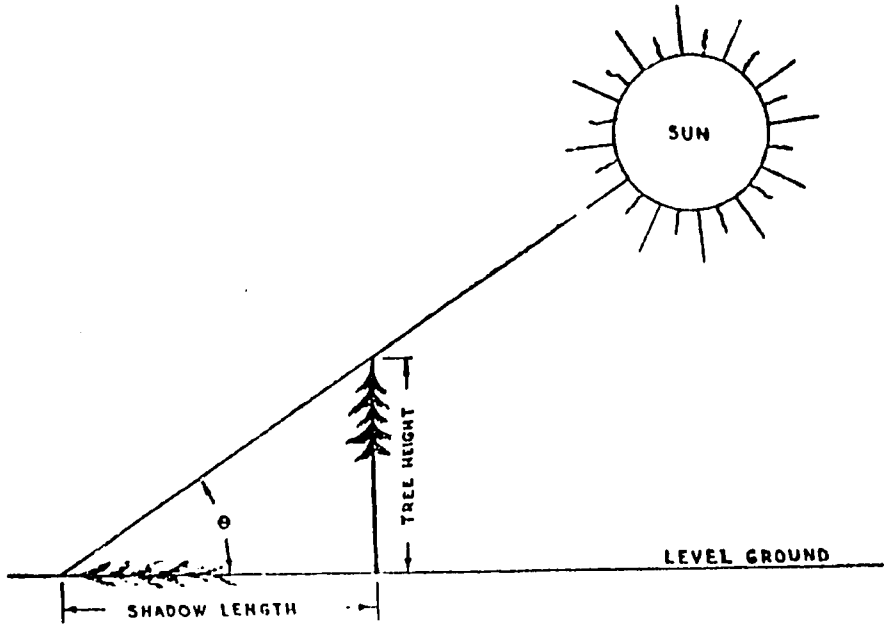


Fig. 32—*Diagram showing relationship between the angular elevation of the sun, shadow length and tree height.*

X

Area, Distance, Slope and Density Measurements

Area Measurements

Aerial photographs are often used for forest delineation and area measurement particularly in flat country where tilt is less than 3° and where the variation in scale due to ground relief is minimum. Such photographs are superior to contour maps for area measurement because they depict a precise record of forest condition, vegetation types, age and density classes and species distribution. All this information is obtainable from aerial photographs, but it needs to be transferred to contour maps either from the photographs or from field inspection and, therefore, it is most likely that the error committed in transferring the essential information to the maps may exceed the error in mesurement of area on the photographs having some tilt and minor scale variations. In rough, mountainous country it is advisable to transfer forest types to base maps for area determination because the scale variations are generally too large to permit correct area measurement directly from aerial photographs.

Area Measurement Devices

Area can be measured on aerial photographs by the following devices:

1. Polar planimeter.
2. Weight apportionment.
3. Transect.
4. Square grid.
5. Dot grid.

Polar Planimeter

A planimeter is an area measuring instrument which has a rotating wheel with a vernier scale attachment and long and short arms. The pointer is carefully run around the boundaries of an area in a clockwise direction for two or more times and the readings are then averaged. On the vernier scale, the area in square inches is read and converted to desired units, usually acres on the basis of a photo or map scale. This method is considered to be a standard for area calculation because it produces accurate measurements if carefully used. Since the method is tedious and time consuming and slight carelessness may produce significant error, it is seldom used in photogrammetry.

Weight Apportionment

This method is based upon the contention that the weight of each unit is directly proportional to its surface area provided the thickness of the paper is

constant. This method of area measurement involves the preparation of photostat copies from the base map or photograph. The photostats are then trimmed so as to include only the area of the project. They are then weighed. Each area is then cut out with a sharp knife and sorted (according to its classification) and weighed. Once the total area is known and weight of the entire area is found out, the area of each classification can be worked out by simple mathematical relationship.

$$\frac{a}{w} = \frac{A}{W}$$

Where: a = area of a particular type.
A = total area.
w = weight of a particular type.
W = total weight.

Transect

This method is based upon the principle of proportion. It involves the running of equi-distance parallel lines through the tract whose area is required to be measured on a map or photograph. Since the relationship between total area and the area of any particular type is essentially the same as the relationship between the whole transect and the transect passing through that particular type, the area is determined by the following proportion:

$$\frac{a}{A} = \frac{t}{T}$$

Where: a = area of a particular type.
A = total area.
t = sum of transects passing through that particular type.
T = sum of all transects.

When the total area of the tract is known and "t" and "T" are measured on the photo or map, the value of "a" can be calculated by the above relationship.

Square Grid

Square grid is nothing more than a transparent sheet having small squares, each representing definite acreage depending upon the scale of the grid. It is very much like graph paper in which one-inch squares are divided into 100 smaller squares. If the scale of the map or photograph is 1"=1 mile, each of 100 squares will represent an area of 6.4 acres on the map or photograph. In actual practice the transparent grid is placed over the photograph and the number of small squares falling in each forest type are counted. The area of each type is then determined in the manner to be explained in connection with the dot grid device.

Dot Grid

Dot grid (Figures 33 and 34) is a further modification of square grid. As is apparent from the name, this grid indicates equal size dots which are equidistant from each other. Each dot represents a known area when used for a particular photographic scale. Suppose each dot represents one-acre area and the grid is

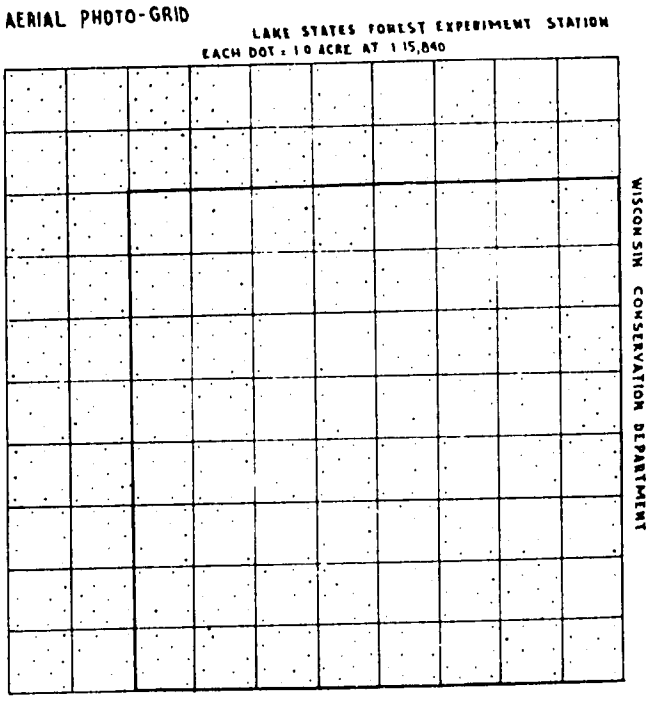


Fig. 33—*Aerial photo dot grid. Each dot represents* 1.0 *acres if used for a photograph of scale* 1:15,840.

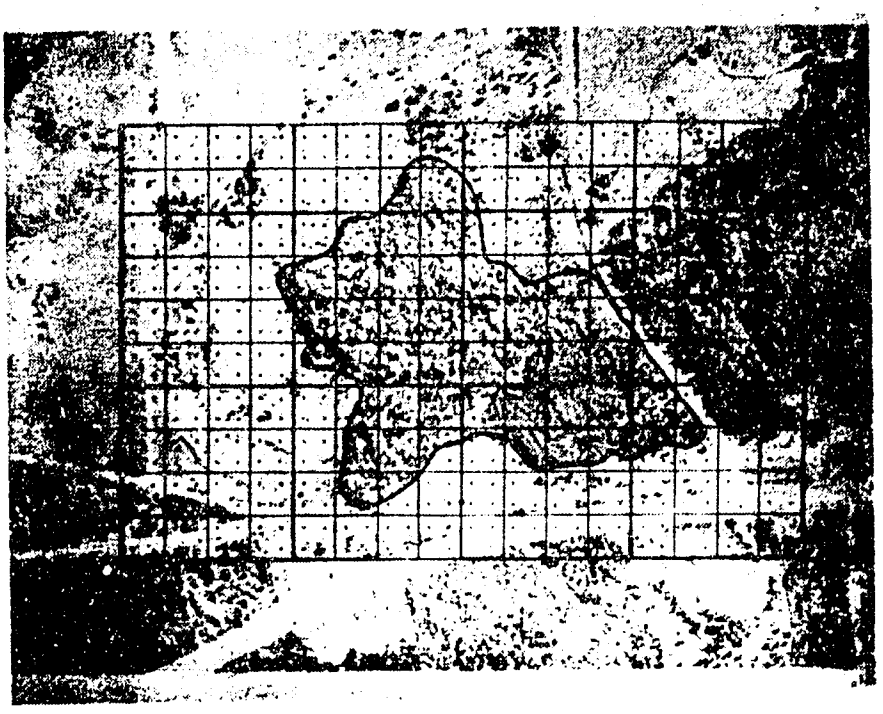


Fig. 34—*Dot grid positioned over a photograph for acreage determination. The delineated stand measures* 25 *acres. Photo scale is* 660 *feet per inch.*

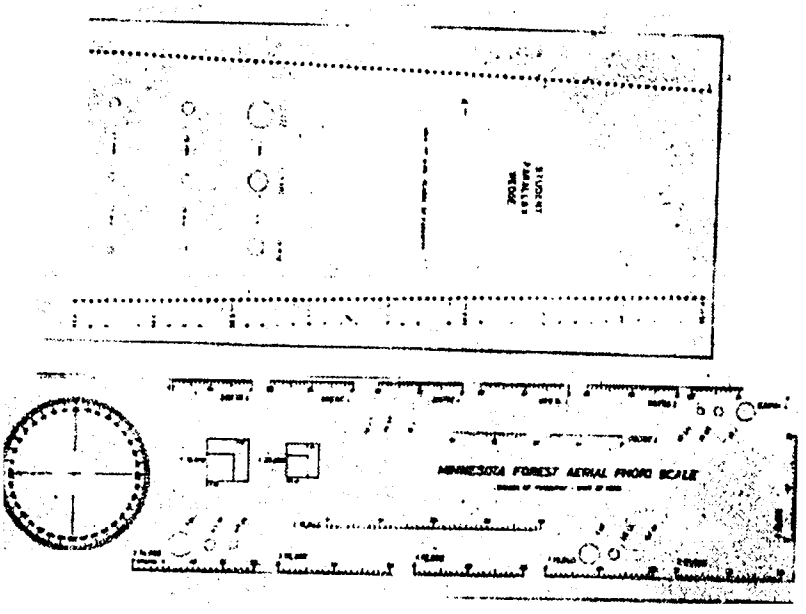


Fig. 35—*Minnesota forest aerial photo-scale.*

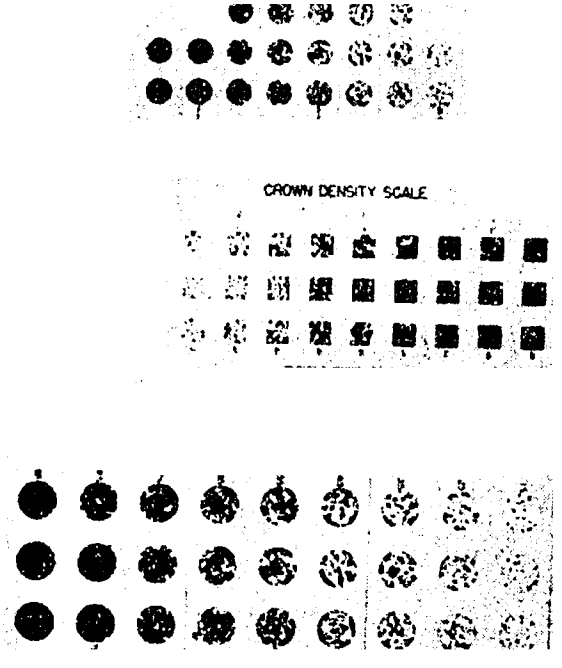


Fig. 36—*Crown density scale.*

originally prepared for area measurement on 1:15,840 photographic scale, but is now for measuring used area on a photo of flat country having a scale of 1:16,460 a scale adjustment would be necessary. This is done by the following formula:

$$\text{Acreage Adjustment Factor} = \frac{\text{Photo Scale Reciprocal}}{\text{Grid Scale Reciprocal}}$$

$$= \frac{(16460)^2}{(15840)^2} = 1.08$$

In other words, each dot on the grid will now measure 1.08 acres instead of 1.00 acres if used for a photograph of 1:16,460 scale.

Distance Measurements

If the scale of the photographs taken over a flat country is known or it is correctly worked out for any particular spot on an aerial photograph of mountainous country, correct distances can be determined between any two points by taking measurements directly on the photographs. For example, at a scale of 1:20,000 a measure of 0.01 inch on the aerial photograph is equal to 16.6 feet on the ground. Aerial photo-scales are available on transparent sheets which are used directly for distance measurements and this eliminates lengthy addition and multiplication. An aerial photo scale showing smallest scale of 1:21,000 and largest scale of 1:14,000 is shown in Figure 35.

Slope Measurements

Slope is defined as a ratio between horizontal distance and vertical distance. If horizontal distance between two points is 100 feet and vertical distance is 10 feet, the slope between these two points will be equal to 10 per cent. On aerial photographs horizontal distance between any two points is measured by measuring the photo distance and by converting this distance to feet at the average photo scale of flat country or the calculated photo scale of mountainous country. For example, if the photo distance is 6.25 inches and the scale of the photograph is 1:9,600, the horizontal ground distance can be calculated by the following formula:

$$\text{R.F.} = \frac{\text{Photo Distance}}{\text{Ground Distance}}$$

$$\frac{1}{9600} = \frac{6.25}{x}$$

$$x = \frac{6.25}{12} \times 9600 = 5{,}000 \text{ feet}$$

Vertical distance between these two points is determined by the parallax formula as explained earlier. The formula is:

$$h_o = \frac{H - h \times x\, dP}{P + dP}$$

For example, if the H-h is equal to 7,969′ and P and dP as worked out from

the stereo-pair is 3.665 and 0.080 respectively, the height of one point over the other will be equal to:

$$h_o = \frac{H-h \times dP}{P+dP} = \frac{7{,}969 \times 0.080}{3.665+0.080} = \frac{637{,}520}{3.745}$$

$$= 170 \text{ feet}$$

Now the horizontal distance between two points is found to be 5,000 feet and vertical distance is equal to 170 feet, the percentage slope between those two points will be equal to:

$$\text{Slope} = \frac{100 \times 170}{5{,}000} = \frac{17}{5} = 3.4\%$$

Density Estimates

Density is defined as the proportion of the forest canopy occupied by tree crowns or the percentage of ground surface covered by tree shadows and sun's rays at noon time when the sun is overhead. It is expressed in per cent or decimal fractions of full stocking. Correct estimation of crown density on aerial photographs is important because it is often applied in making photo determination of stand volume. By making comparison with a crown density scale, it is estimated occularly in 10 per cent classes starting with 5% and ending at 95%. The various types of crown density scales generally used in photo-interpretation and photogrammetry are shown in Figure 36.

A number of factors are known to upset correct estimation of crown density on aerial photographs. Shadow is considered as the most important source. This is particularly true in cases of infra-red photography which registers shadows black, making it difficult to distinguish a shaded part of a crown from the shadow of a gap. Density is also over-estimated on slopes facing away from the sun because the shadows produce an effect as if more space was occupied by the crowns. Another source of error is the displacement of crowns; this error increases as we travel away from nadir of the photograph. The scale of the photograph and the resolution power of the photographs are also important from crown density estimation point of view. Small openings or gaps will not be resolved or seen in small-scale photographs and therefore density will be over-estimated.

The cumulative effect of resolution, shadows and scale results in a tendency for the observer to over-estimate crown density. This can only be counter acted or minimized by practice and the experience of working with aerial photographs under a stereoscope.

XI

Photo-equipments

The equipment used in photo-interpretation and photogrammetry can be classified in three main categories:

Photo-flying equipment.
Photo-interpretation equipment.
Photo-mapping equipment.

Photo-flying Equipments

Aircraft

Almost any type of aircraft including helicopters can be used for taking aerial photographs provided they fulfil the following essential requirements:

1. The aeroplane should be capable of flying at low to moderate speed (e.g. 100 to 200 miles per hour) at approximate heights of 10,000 to 20,000 feet above mean sea level. A higher flying altitude may be required for taking photographs in high mountainous country like Himalayas.
2. The aeroplane should be stable so that it experiences minimum vibrations while on flying missions.
3. For taking vertical photographs, the camera would require a window or opening in the floor of the cockpit of the aeroplane. A vertical view finder, if separate from the camera, would require another small opening close to the main camera opening. The facilities must exist in the plane before it is used for aerial photography.
4. There should be ample room in the cabin or cockpit for equipment and freedom for operation. A space of four feet wide and six feet long is enough for any of the standard cameras and accessories.

The requirements of the aircraft used for taking aerial photographs have been summed up in the *Manual of Photo-grammetry* of the American Society of Photogrammetry as follows:

> "An airplane to be suitable for aerial mapping must have requisite speed, a high rate of climb, good stability while in flight, unobstructed vision in all directions for navigation and identification of landmark features, a range commensurate with the size of the project, and a ceiling equal to or higher than the highest altitudes specified. It should be able to remain in the air long enough to take advantage of suitable photographic time, roomy enough to accommodate all necessary equipment and powerful enough to carry its full load to the flight height required. It should be so designed as to give the pilot and photographer maximum comfort so as to reduce fatigue and maintain a high level of efficiency. The airplane should be economical in operation and should be so constructed as to accommodate the camera or cameras in the positions necessary to obtain the type of photography desired."

Since aeroplane used for aerial photography have proper specifications, almost all aerial surveying companies have special aircrafts designed and manufactured for obtaining aerial photographs. Light single-engine (i.e. Cessna 182), light to medium twin-engine (Cessna 310 or Skymaster, Figure 37) or outdated military aircraft are most commonly used for commercial photography. For military operations, sophisticated jet-type planes (i.e. U-2, F-86) are used. Helicopters are also used for special types of aerial photography because they exhibit superiority over fixed wing aircraft in situations where low-altitude flying is required. Their ability to maintain horizontal flight at low speeds makes them especially valuable for taking large scale photographs of spot locations such as scattered forest inventory plots or small plantations and clear cut areas.

Aerial Camera

Aerial camera is defined as camera especially designed for use in aircraft. There are various types of aerial cameras but the most commonly used are single lens cameras. It consists of three main parts: a body, a cone, and a magazine (Figure 38). The body has the following constituent parts:

1. Filter.
2. Front lens element.
3. Shutter.
4. Diaphragm.
5. Rear lens element.

The magazine has three constituent parts: supply spool, take up spool and platen. The cone is the intermediate part of the camera which keeps the camera body and magazine at a definite distance apart from each other. When the camera is focused at infinity, the lens gathers light rays reflected from the objects and transmits them in an orderly fashion to the light sensitive area known as the film. The shutter assembly serves to regulate the amount and duration of light reaching the film when making an exposure. Since an aerial camera is used for taking photographs from a moving aircraft, it should have a very effective shutter which should open for a minimum length of time to prevent blurring of the images due to movement of the airplane and also ensure taking of the whole picture at one time. A focal plane shutter is unsatisfactory because the film is progressively exposed while the aircraft is moving, resulting in the distortion of the images. For example, if a slit 0.25 inch wide is used to give each portion of the negative an exposure of 1/40 second, there is a lapse of 0.09 second between the times the opposite sides are exposed, during which time an aeroplane travelling at 200 miles per hour has travelled about 30 feet.

In addition to a fast and effective shutter, the aerial camera should have a high-grade lens which should admit sufficient light at the required shutter speed and must be adaptable to the particular camera design and the film used and should have low distortion characteristics.

Types of Camera

Aerial cameras can be classified in a number of ways:

1. By lens type: single lens, multiple lens.
2. By angular field: normal angle-up to 75°; wide angle-75° to 100°; and, super wide angle-100° and above.
3. By focal length: short-up to 6 inches; normal-6 to 12 inches; and, long-more than 12 inches.
4. By use: reconnaissance, mapping and special.

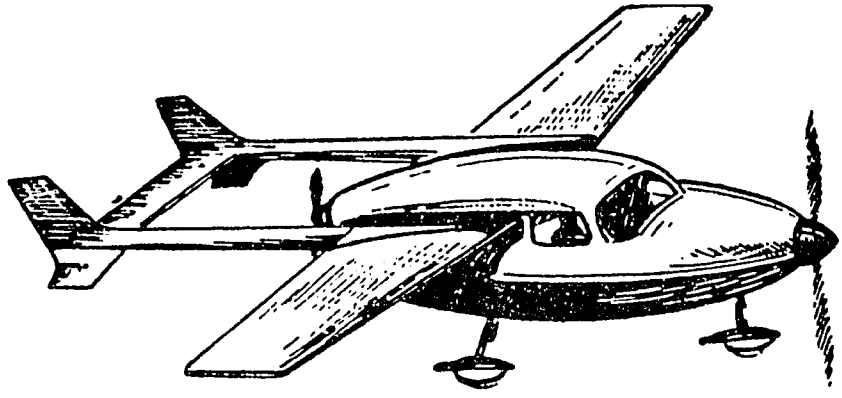


Fig. 37—*A twin-engine Cessna Skymaster. It has a cruising speed of about 180 m.p.h., a rate of climb of 1550 feet per minute and a ceiling of over 20,000 feet.*

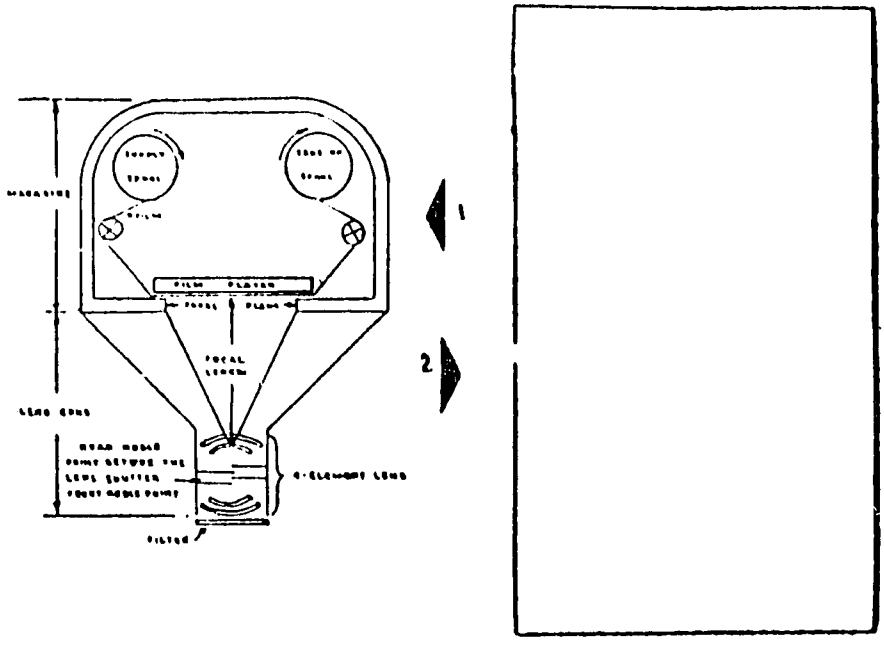


Fig. 38—*Cross-section of a typical aerial camera.*

The choice or selection of any particular type of camera would depend upon the need of the photo-interpreter. For example, the cameras used for low-altitude high-speed photography must have wide angle lenses, fast shutter, image-motion-compensating magazines and short cycling times. For higher altitude photography long-focal length cameras are used to provide a reasonable scale and good ground resolution.

The most commonly used cameras for aerial photography are Zeiss EMK A 15/23 and Wild RC-8. These cameras are capable of exposing panchromatic, colour, infra-red or false colour film without changing the focal poisiton or introducing significant variance in distortion.

Almost any camera used for aerial photography has to fulfil certain specifications. They are:

a. The focal length of the camera should be normally 6,8 ,25 or 12 inches.
b. The camera should ordinarily expose 9 X 9 inch image negatives and the focal plane and fiducial marks be permanently fixed on the photographs in rigid orientation with one another.
c. The platen against which the film is pressed at the time of exposure should not depart from the true plane by more than plus or minus five-ten-thousands of an inch (0,0005").
d. The lens should be capable of resolving lines in any orientation spaced twenty lines to the millimeter at the centre of the field and lines in any orientation spaced ten lines to the millimeter at 5° or 7,5° intervals lying between the centre and out to and including 30°.
e. The radial distortion should normally not exceed plus or minus 0,03 mm out to 30° and 0,10 mm at 35°.

Photo-interpretation Equipments

The list of equipment required for photo-interpretations is given in Chapter V. One of the items included in that list is a stereoscope. Since there are different types of stereoscopes available to the interpreter and the choice of any particular stereoscope would be influenced by so many considerations, it is worthwhile to include a brief description of each type at this stage.

Lens Type Stereoscope

Lens stereoscope is the simplest optical instrument for viewing objects in three dimensions. It consists of two magnifying lenses which are fitted in a stand and are used for viewing objects on stereo-pairs. The height of the stand is so adjusted that the distance between the eyes and the photograph is equal to the focal length of the stereoscopic lens. The enlargement of lens stereoscope normally varies from 2.5 to 3.5 times. The great advantage of this type of stereoscope lies in the fact that it is cheap and can easily be carried. Moreover, it is very simple to operate under diverse conditions. Its major disadvantages are its limitation as to the range of magnification, difficulty of annotating photos while observing, narrow fields of view, and limited capability of spreading photos while observing (distance of spread is approximately equal to or less than interpupillary distance). Simple type of lens stereoscope is shown in Figure 39.

Prism Type Stereoscope

This type of stereoscope consists of two thin prisms which are fixed in a

Fig. 39—*Pocket size lens stereoscope for viewing overlapping pairs of aerial photographs.*

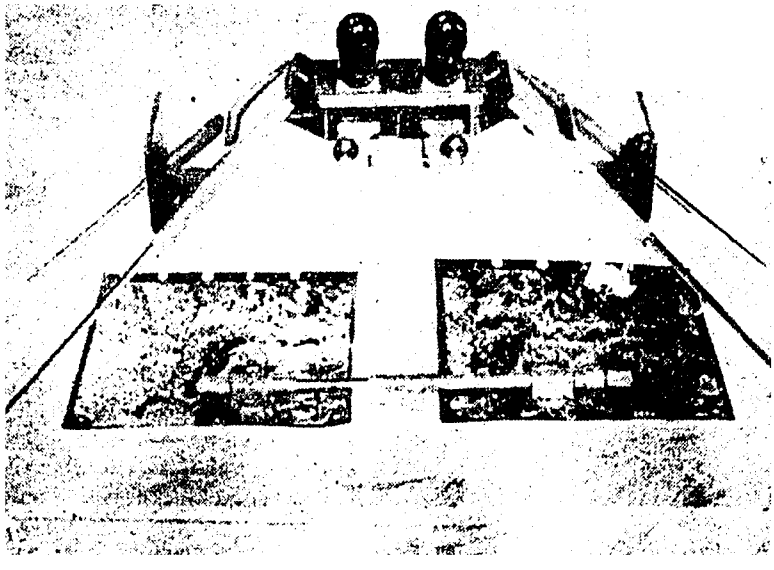


Fig. 40—*Modern mirror stereoscope with inclined magnifying binoculars.*

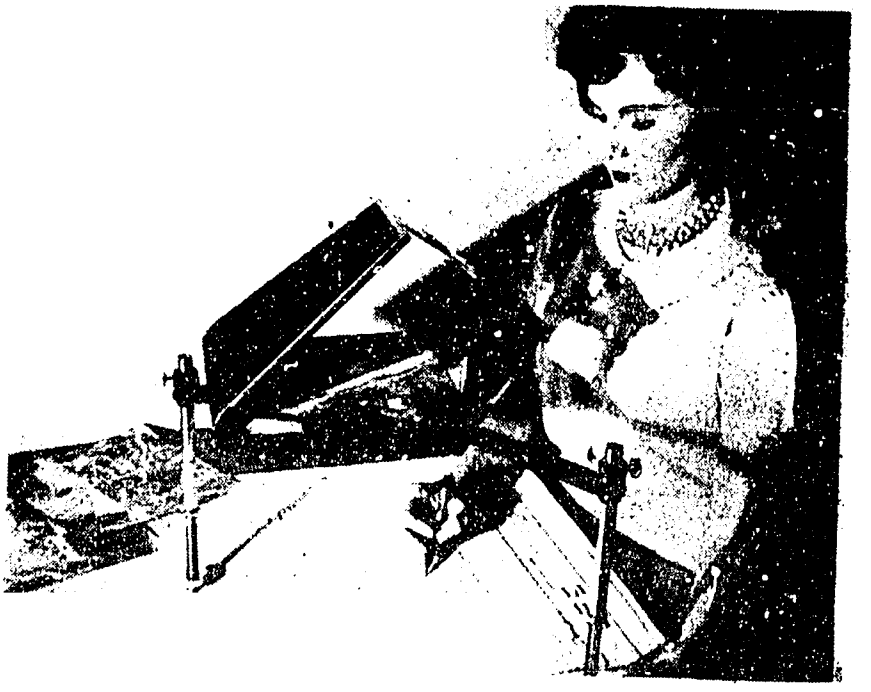


Fig. 41 (a)—*Vertical sketchmaster. Photographic detail is transferred from photo to base map.*

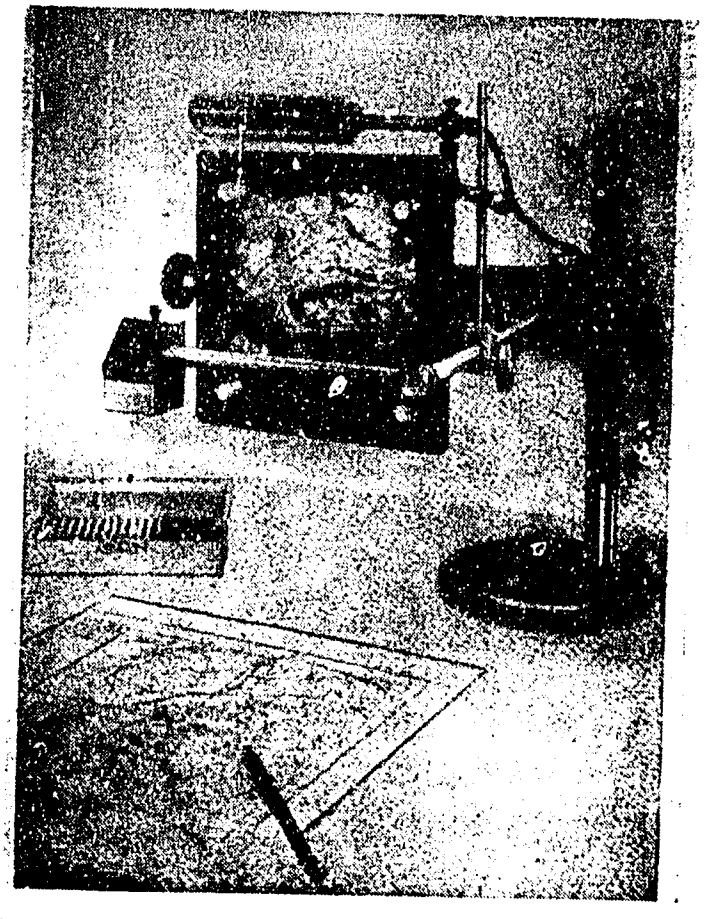


Fig. 41 (b)—*Aero-sketchmaster. This is also used for transferring detail from single photograph to a base map.*

stand and are used for viewing stereo-pairs. In photo-interpretation this type of stereoscope is not widely used because no magnification is afforded. Moreover, a single pair of prisms viewed cannot in this manner deflect vision sufficiently far off to permit the observer to study the entire overlap of a stereoscopic-pair of photographs close at hand without seriously distorting the images.

Mirror Type Stereoscope

This is also known as reflecting stereoscope because images are reflected by passing through various mirrors before reaching the eyes. A mirror stereoscope is shown in Figure 40. The superiority of this stereoscope over the other two types of stereoscopes lies in the fact that it affords full separation of the stereoscopic pair of photographs and thus provides full view of the entire stereoscopic model under normal observing (no magnification) conditions, and allows the use of mounted opaque prints as well as positive and negative transparencies.

Its major disadvantages are:

1. There is a relative loss of illumination because of the number of glass surfaces involved and the distance the light rays have to travel.
2. It is more costly than the lens type especially when binoculars are required for producing comparable magnification.
3. It is less portable than the lens type.
4. It requires more maintenance than the lens type, especially the mirror surfaces which are subject to damage due to excessive handling and exposure to moisture and other environmental conditions.

Photo-mapping Equipments

As already mentioned in Chapter VI an aerial photograph is not a map because of image displacement due to relief, tilt and other causes. If a map is to be prepared from aerial photographs, the topographic details have to be transferred from photographs to base map. This transfer of detail is effected by the help of various instruments. These instruments are classified into the following categories:

Single photo plotters
Stereo photo plotters

Single Photo Plotters

Instruments used for the transfer of planimetric detail from single photographs are divided into two main groups:

1. Sketchmasters
2. Reflecting Projectors.

Although these instruments are quite different from one another in principle, construction and appearance they produce more or less identical results.

Sketchmasters

A sketch master is also known as camera lucida. The term "camera lucida" is applied to any instrument in which two images are superimposed by means of a semi-transparent mirror and the detail is then traced out. In simplest form a camera lucida consists of a semi-transparent mirror and a photograph mount. Since the semi-transparent mirror is partially

silvered, it both reflects and transmits light at the same time. The eye, therefore, can see a map through the mirror and it also sees a photographic reflection in the mirror. When the two images appear to be super-imposed, then the detail is traced out from one image to the other.

The various models of camera lucida available for transfer of detail are shown in Figures 41(a) and 41(b). The lotter is available in Aerial Forest Inventory Project, Peshawar. Their cost varies from Rs. 2,000 to Rs. 3,000. They are portable and are relatively cheap. They work well when used for comparatively flat country. They do not remove photographic displacement and a very small amount of enlargement is possible with them.

Reflecting Projector

Reflecting projectors are of two types:

(i) Overhead type.

(ii) Table type.

The principle and mechanism of operation is practically the same in both cases except that in the case of the table type projector the image is not reflected directly on the map surface. Projected images of photographic prints or other opaque material are super-imposed on a map or map manuscript and the detail is then tracedout.

Overhead Projector

This is shown in Figure 42. In this case the photographs are individually placed in a special chamber and the images are projected down to the map or document placed on the drafting table. The image projected can be set to the same scale as the original or to any other scale up to several times reduction or enlargement. The enlargement, reduction and focusing is done by means of a lens which can be raised or lowered with the help of a special mechanism. The principal requirements of this instrument are:

(a) Light source should be sufficiently bright to reflect a clear photographic image.

(b) The projector should have a cooling mechanism to remove the heat generated by the light source.

(c) The optical system should be adequate.

(d) The instrument should have sufficient range to project the photographs at the required changes of scale.

The major disadvantages of this instrument are that it can only be used for flat country. It is not portable, requires a dark room and above all, it does not remove topographic displacement.

Table Type Projector

It is a reflecting type of projector which is built in a table. The photographs are singly placed face down under a cover plate on the left side (Figure 43) and the images are reflected horizontally by a tilted mirror through a lens and onto another tilted mirror that reflects the images to the large glass plate on the right for direct tracing. The material being reflected may or may not be transparent but the tracing material must be transparent or semi-transparent. Tracing paper, tracing cloth or frosted plastics can be used for this purpose. The light source consists of reflector flood lamps cooled by an electric fan. Scale is controlled and adjusted by a worm gear, shaft and cable and the focus is controlled by a sprocket

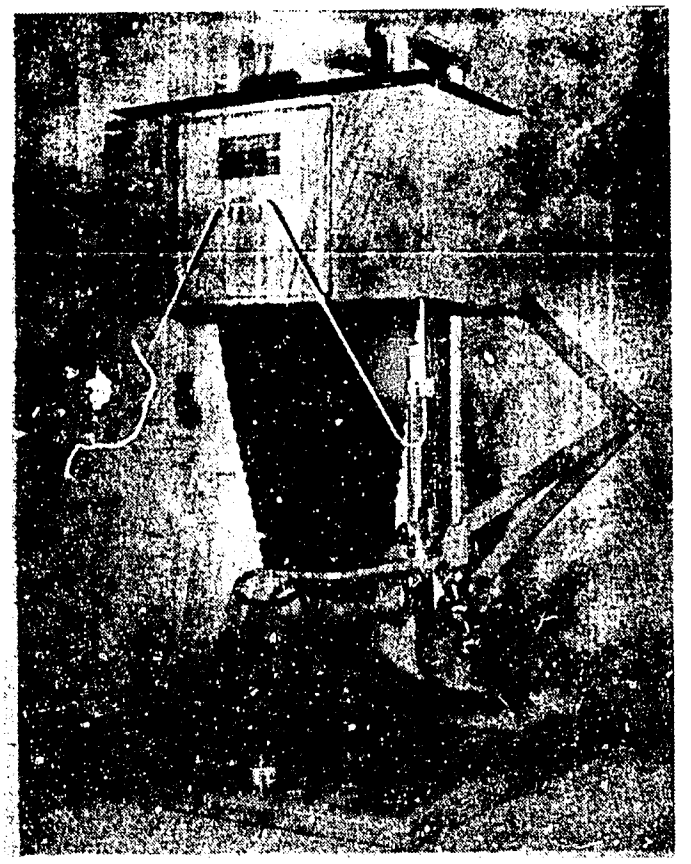


Fig. 42—*Overhead reflecting projector.*
A contact print can be placed behind the spring-held panel and detail traced out on a base map positioned below.

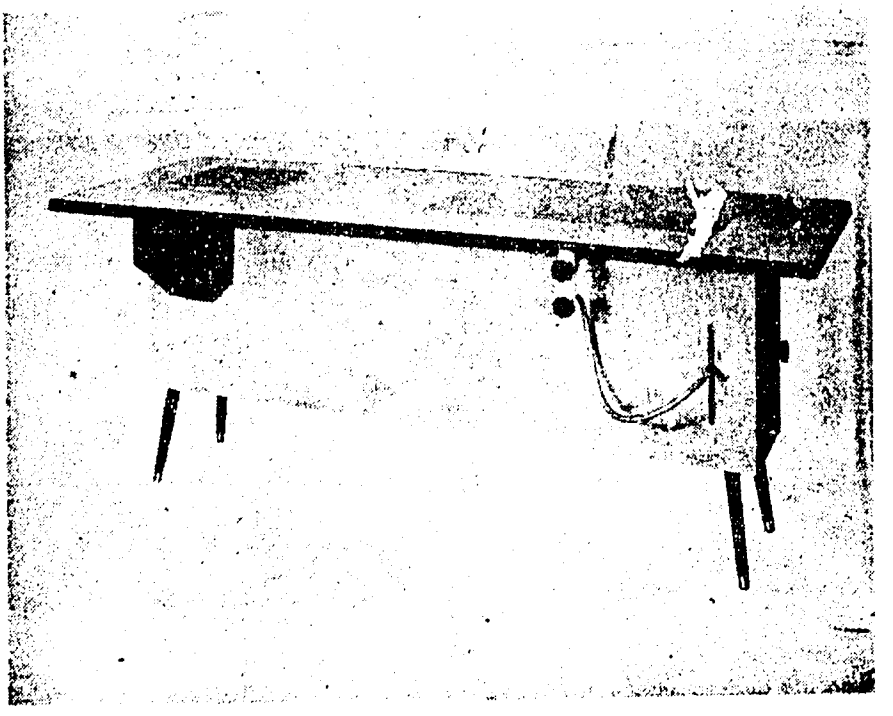


Fig. 43—*Table-model reflecting projector.*
A photograph is placed face-down under the cover plate on the left and the images are projected to the large glass plate on the right for direct tracing.

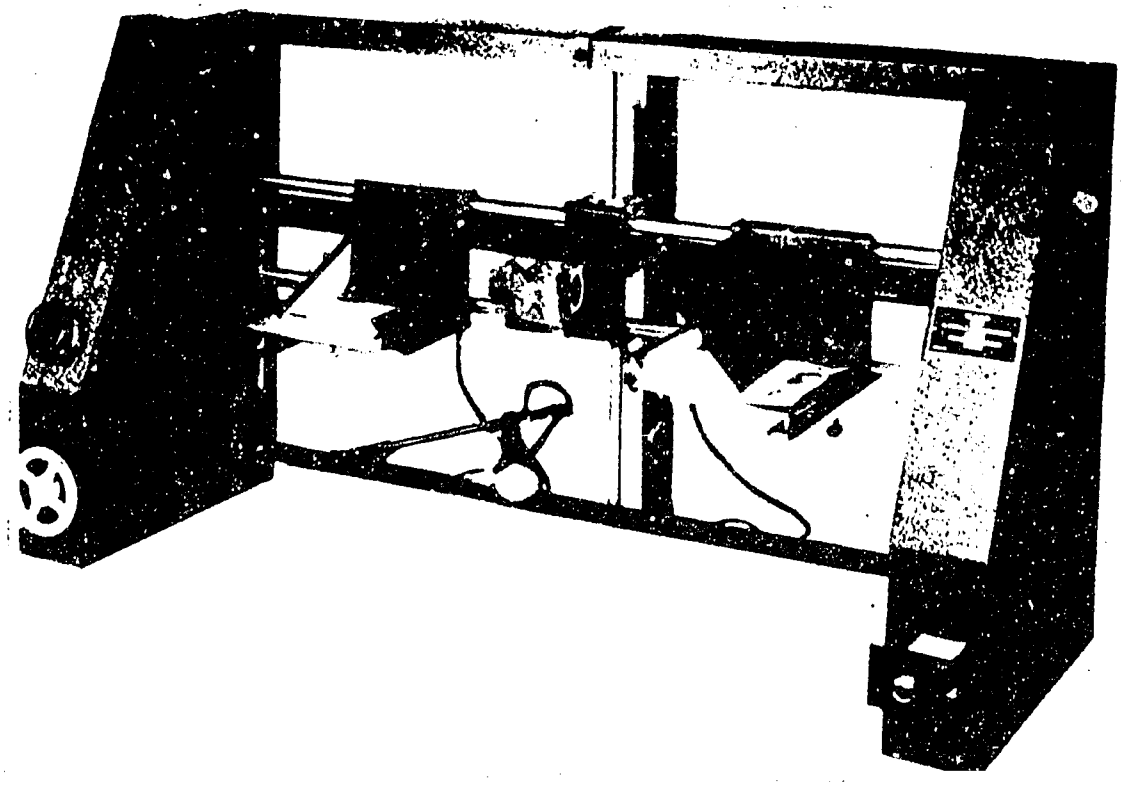


Fig. 44 (a)—*Multiscope. This instrument is available in Aerial Forest Inventory Project and has been used for the preparation of maps from aerial photograph.*

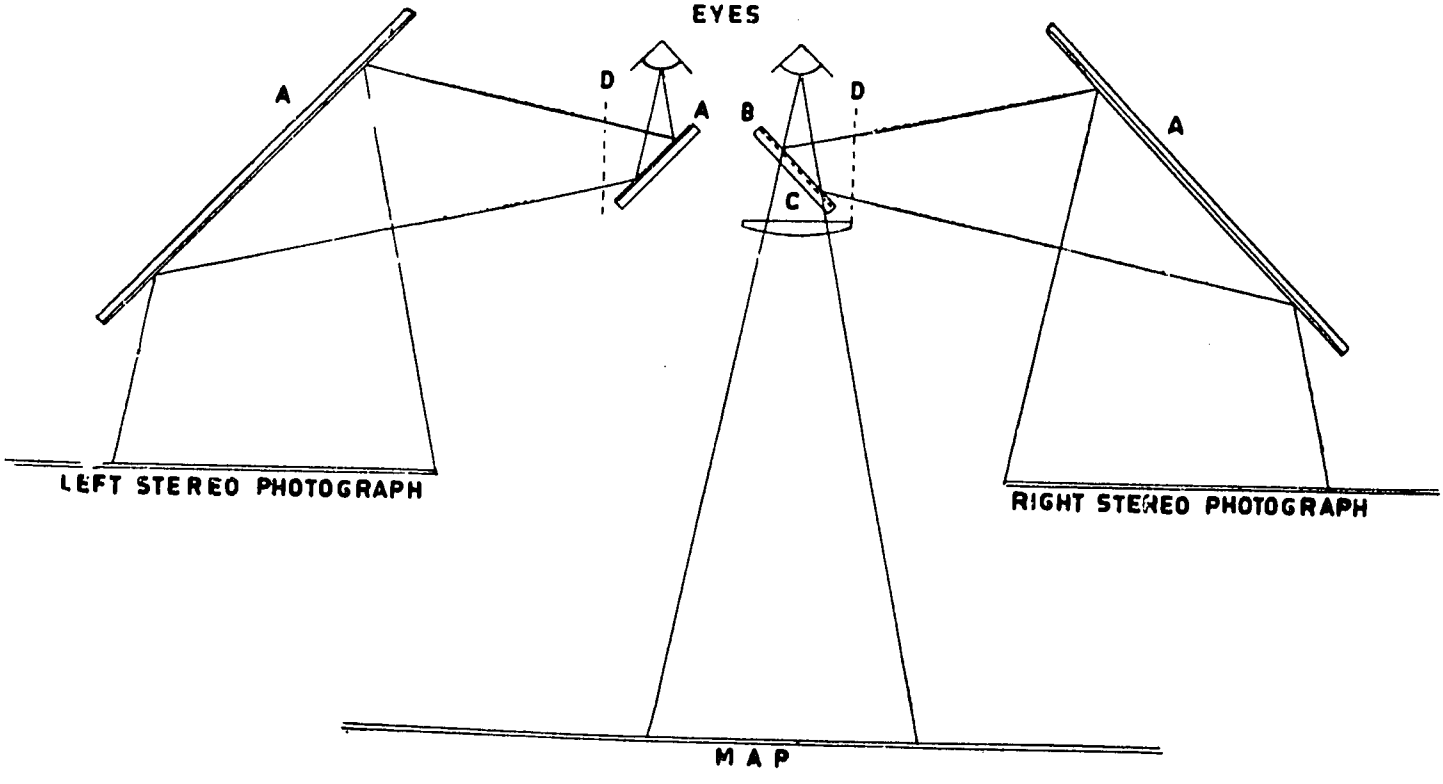


Fig. 44 (b)—*Diagram showing principle of working with multiscope.*

and chain. The projector has almost the same advantages and disadvantages as the overhead type projector. The only difference between the two projectors lies in the fact that the table type requires transparent to semi-transparent map paper because the images are not directly reflected on the map surface.

Stereo-photo Plotters

The instruments included in this category are called stereo photo plotters because they provide the facility for making stereoscopic measurements on aerial photographs. They range from simple devices limited in operation to the measurement of parallax differences to the more complex instruments which are highly precise and are used mainly for contour mapping. For the purpose of this book comparatively simpler instruments will be described.

The stereo photo plotters can be grouped in two main categories:

1. Paper print plotters.
2. Dia-positive (glass plate) plotters.

Paper Print Plotters

Paper print plotters are further classified into four main types.

(i) Multiscope.
(ii) Radial line plotter.
(iii) K.E.K. plotter.
(iv) Stereotope plotter.

Multiscope

Multiscope is a very simple instrument and is used as a stereoscopic plotter in Aerial Forest Inventory Project. This instrument is show (Figs. 44 (a) and 44 (b). The adjacent photographs in the same flight line (i.e., a stereo pair) are placed on their respective tables of the instrument so that the overlapping positions are towards the centre and the shadows fall towards the observer. The photograph tables are then adjusted so that the flight lines are lined up parallel to the long side of the instrument. The observer looks into the eye-piece and, by adjustments, obtains stereo-image which is projected to the map placed over the table under the instrument. The base map is shifted to and fro so that the photographic features completely super-impose the map features. The required detail is then transferred to base map by direct tracing. There are various combinations of vertical and horizontal scales of the instrument for various ratios of the map and photo scales. Since photographs do not have constant scale, the stereoscopic assembly and base map need frequent shiftings in order to achieve best results under various conditions.

Radial Line Plotter

The principle of a radial line plotter is the same as that of radial line templet control. The technique or operation is more or less similar to that of plane tabling or transit triangulation. A simple radial line plotter consists of a precision first-surface mirror stereoscope mounted over two shiftable photo-tables, each containing a pair of radial arms which are connected to a parallel bar and linkage. The stereoscope is adjusted so that the line of sight is vertical onto the centre of each of the photo-tables. Over each of these photo-tables is a transparent arm with a scribed red line which radiates from the centre of the photo-

table. This transparent arm is connected at its outer end to another arm of metal, underneath the photo-table. The metal arms also radiate from the centre of the tables and are slotted on the under side, the slot being directly under the scribe red line.

The two metal arms are connected by a parallel bar which maintains contact with the arms by means of two sliding pins which engage the slots. To the parallel bar is fastened a plate which carries the pencil and scale adjustment. As the pencil is moved, the pins slide along the radial arms and revolve them.

In operation, the stereoscopic photographs are viewed through the stereoscope which brings the three dimensional model into view. Super-imposed on the stereoscopic model are the two pivoting red lines which radiate from the centres of the photographs. As these lines radiate from different centres, they cross each other, and it is this intersection of the crossed lines that is used for plotting. As the pencil on the bar is moved, the intersection of the radial lines moves in the same direction. By keeping the intersection of the radial lines on the detail to be mapped, the detail is drawn with the pencil directly on the map sheet, to scale and with the distortion due to difference in elevation removed.

To operate the plotter, the proper pair of stereoscopic photographs are placed on the photo-tables with their centres over the centre of the respective table. A centre pin is placed through the radial arm, the photo and the photo-table. The photos are then oriented by revolving them until the transferred centres of the matching photos as well as their own centres are aligned on the longitudinal axis of the plotter. The photographs are then fastened down and oriented with the map sheet. The drawing scale of the plotter is changed by varying the distance between the two sliding pins on the ends of the parallel bar. The right hand pin may be moved manually for rough adjustment. The left-hand pin is moved by means of a control on the pencil plate. It is used for the fine adjustment. The scale range of the plotter varies from slightly over the full size of the photographs to one-third of full size. By using this scale adjustment and moving the plotter on the map sheet, the control points on the photos can be brought into coincidence with the points on the map. When two or more points have been brought into coincidence, the detail on the photographs may then be drawn on the map to the proper scale and with the elevational displacements removed.

The only disadvantage of this instrument lies in the fact that it does not remove photographic tilt. The radial line plotter is shown in Figure 45.

K.E.K. Plotter

This instrument (Figure 46) has been designed to perform the functions of a plotting instrument that is relatively inexpensive yet capable of automatically correcting tilt and displacement of the photographs, so that accurate planimetric and topographic maps are drawn to the scale in one operation. In other words this instrument is capable of removing topographic displacement and photographic tilt, and in addition to this, contour lines can be prepared with it.

The K.E.K. plotter consits of the following basic elements:

(a) A front surface mirror stereoscope is mounted so that the principal line of sight from each eye falls vertically onto the centre of each photo-table, when the tables are level.

(b) A pair of movable photo-tables that are mounted in the plotter so that they can be raised or lowered vertically, with relation to the stereoscope by means of a hand wheel on the left side of the plotter. The photo-tables are also provided with movements for rotating, tilting, and

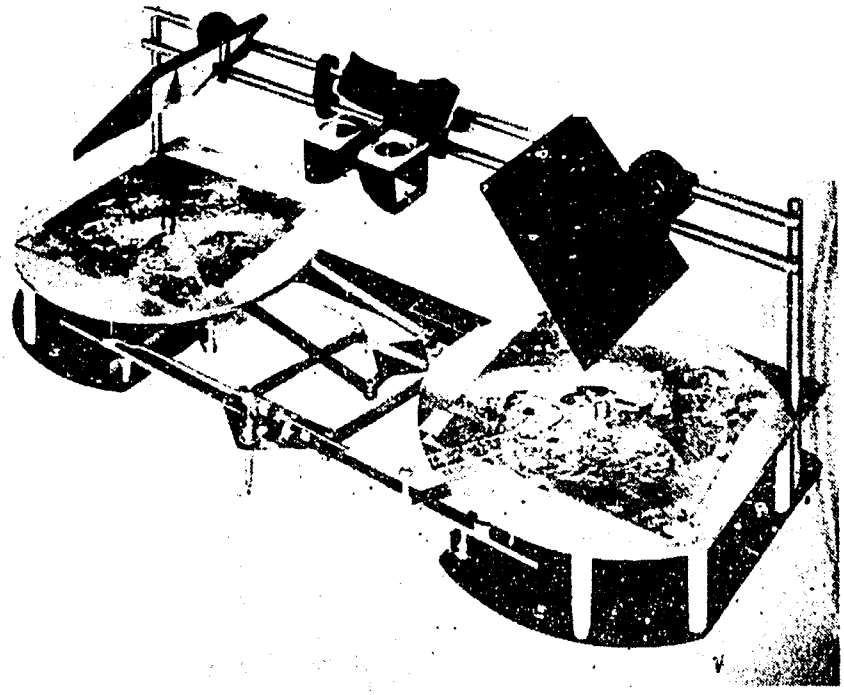


Fig. 45—*Radial line plotter (also known as radial planimetric plotter).*

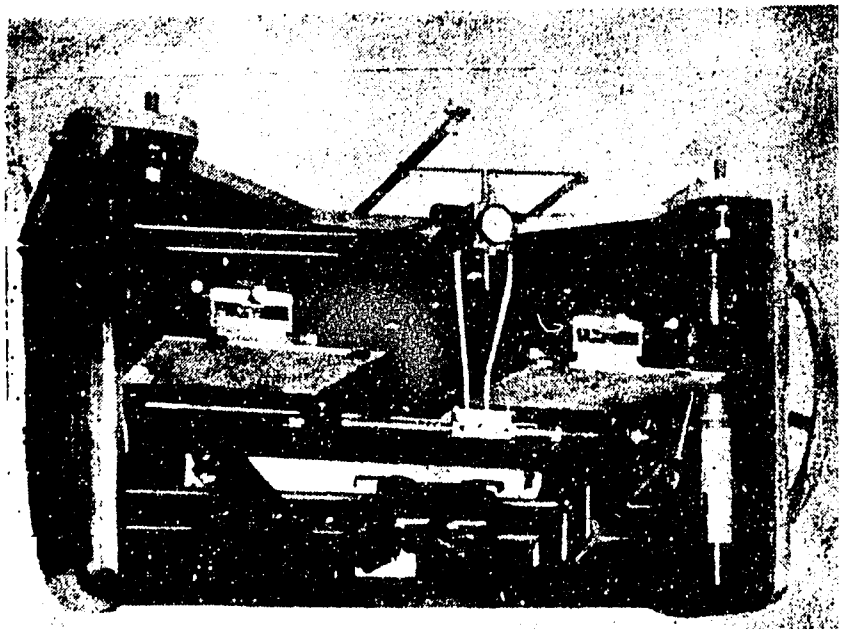


Fig. 46—*K.E.K. plotter. It is a relatively inexpensive floating-mark instrument for drawing planimetric and topographic maps to scale in one operation.*

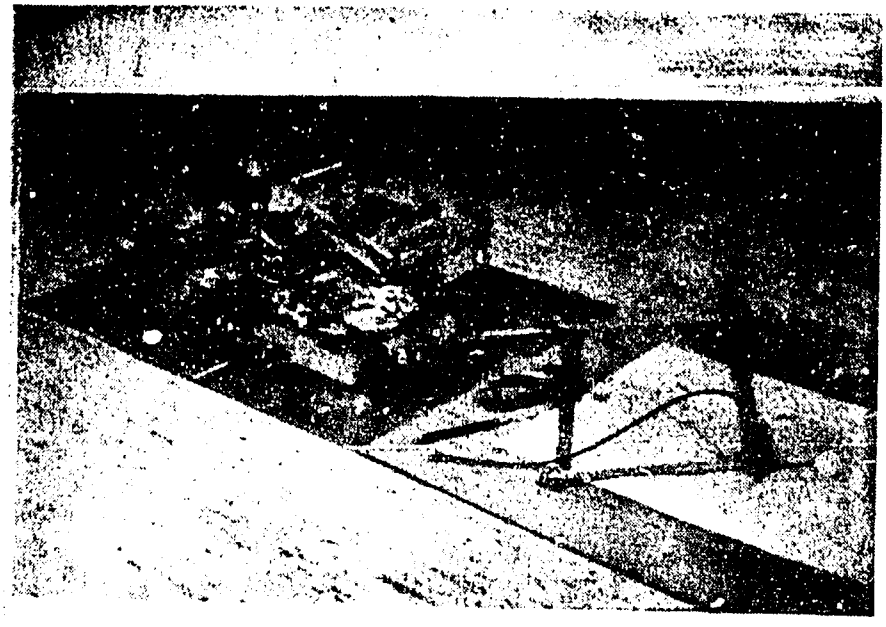


Fig. 47—*Stereotope. A third-order plotter instrument designed for topographic mapping from paper prints. This instrument is available in Aerial Forest Inventory Project and has been used for mapping.*

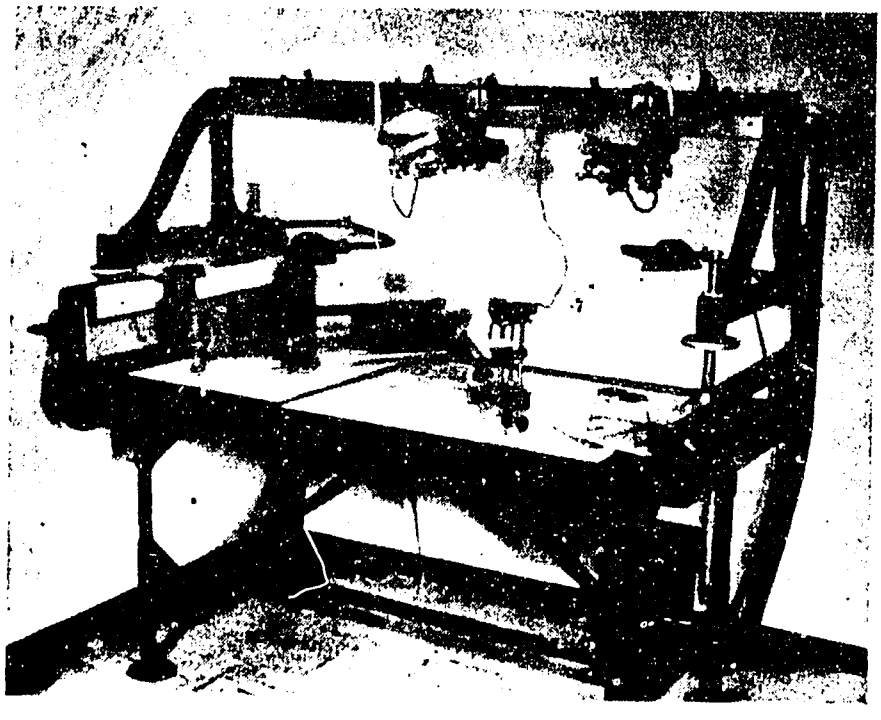


Fig. 48—*A direct-viewing double-projector (dia-positive plotter).*

tipping the photographs in order to reproduce the relative position of the camera at the time of the original exposures.

(c) A floating mark which consists of a dot in the centre of each of two lens discs which are interposed in the line of sight, between the stereoscope and the photo-tables.
The floating mark is mounted on a drawing arm and adjusted so as to move freely in a horizontal plane.

(d) A drawing arm that restricts the floating marks to an exact horizontal plane and keeps the two marks parallel to each other. This horizontal movement can be enlarged or reduced by the use of a pantograph that is an integral part of the drawing assembly.

The theory and operation of this instrument is considered beyond the scope of this book.

Stereotope

The instrument is a portable stereo plotter which utilizes a system of mechanical analogue computers called rectiputers for removal of tilt and relief displacements of nearly vertical photographs. Thus, it facilitates the compilation of planimetric and topographic detail in one continuous operation.

The basic elements or components of this instrument are the stereoscope, the photo-carriage, the photo-holders, the parallel motion linkage, the intermediate base plate, the tracing pad and the pantograph.

Theory and operation of this instrument is considered beyond the scope of this book. This instrument is shown in Figure 47. A simplified version of this instrument known as stereospret is used for planimetric plottings.

Dia-positive Plotters

These are precision instruments or stereo plotters which utilize positive transparencies printed on glass plates, rather than film base transparencies for the purpose of the projecting photographic image. The glass plates used for this purpose are customarily referred to as dia-positives which means glass plate transparencies with a positive image. Dia-positive plates are readily available in three standard sizes of approximately 2 inches, 4.5 inches, and 9.5 inches square according to the type of plotters to be used. If a double-projection direct-viewing-type instrument is used, it is important to ensure that the surfaces of these plates are placed parallel to the general plane because significant errors in the stereomodel can be caused by minor deviations of the photographic emulsion from a plane surface. A lack of parallelism between the two surfaces of the glass plate can also cause significant errors.

The double-projection direct-viewing plotters, regardless of type or manufacture, consist of two or more optical projection devices which remain suspended in space through a supporting frame. The design of the frame varies with the manufacturer. The frame, however, is sufficiently rigid and stable to maintain the projectors in their absolute orientation for extended periods of time without the slightest-displacement of the original model orientation.

The frame, by having adjustable supporting screws, also serves to aid in the absolute orientation of the projection units. These are very essential requirements and considerable mechanical engineering ingenuity is devoted to the design of the supporting frames.

A new model of double-projection direct-viewing plotter is shown in Figure 48.

GLOSSARY

These terms are derived largely from *Manual of Photographic Interpretation* of the American Society of Photogrammetry.

Aerial Photograph	Any photograph taken from the air; sometimes called aerial photo or air photograph. In this book, it is assumed to mean vertical aerial photograph.
Air Base	The line joining two aerial camera stations.
Base, Acetate	A transparent plastic material which is coated with a photographic emulsion. It is composed of cellulose acetate and is practically non-flammable.
Base, Film	A thin, flexible, transparent sheet of cellulose nitrate, acetate, or similar material which is coated with a light-sensitive emulsion and used for taking photographs.
Calibration	The act or process of comparing certain specific measurements in a camera or other instrument with a standard.
Camera, Aerial	A camera specially designed for use in an aerial vehicle. (The prefix "aerial" is not essential where the context clearly indicates an aerial camera rather than a ground camera.
Contact Print	A print made from a negative or a diapositive in direct contact with sensitized material.
Contrast	In general, the degree of differentiation between tones.
Contrast, Subject	The difference in light intensity between the brightest highlights and the deepest shadow within the scene.
Control	A system of accurate measurements used to determine the distances and directions and/or differences in elevation between points on the earth.

Control, Ground	Control obtained by ground surveys as distinguished from control obtained by photogrammetric methods.
Control, Point	Any station in a horizontal and/or vertical control system that is identified on a photograph and used for correlating the data shown on that photograph.
Copy	The text and illustrative material from which duplicates are reproduced.
Coverage, Stereoscopic	Aerial photographs taken with sufficient overlap to permit complete stereoscopic examination.
Crab	The condition caused by failure to orient the camera with respect to the track of the aeroplane, indicated in vertical photography by the sides of the photographs not being parallel to the principal-point base line. See: drift.
Crown Closure	A photo measure or estimate of the density of a forest stand. As seen on the vertical photograph, crown closure is the percentage of ground area occupied by tree crowns.
Crown Diameter, Visible	The apparent diameter of a tree crown imaged on a vertical aerial photograph.
Datum	A reference element, such as a line or plane, in relation to which the positions of other elements are determined. Also called the "reference plane" or "datum plane."
Definition (optics)	The ability of a lens to record fine detail.
Densitometer	A device for measuring the density of a negative. The instrument measures the magnitude of the light transmitted through the exposed and developed film.
Density	The comparative amount of silver deposited by exposure and development in a given area. It is expressed in terms of the percentage of light passing through the area.
Depth of Field	The distance between the points nearest to and farthest from the camera which are acceptably sharp.
Depth of Focus	The range of distances behind the lens of a camera throughout which the definition of an object at a given distance is satisfactory.

Developer — The solution used to make visible the latent image in an exposed emulsion. In black and white photography the process is one in which the silver halide grains which were exposed to light are reduced to metallic silver.

Diaphragm — The mechanical element of an optical system which regulates the quantity of light traversing the system. The quantity of light determines the brightness of the image without affecting the size of the image.

Diapositive — A positive photographic print on a transparent medium. In photo-grammetry, the term is generally used to refer to a transparent positive on a glass plate used in a plotting instrument or projector.

Diffusion — The scattering of light rays upon reflection from a rough surface, or upon the transmission of light through a translucent medium.

Diopter — A unit of measurement of power of lenses, especially spectacle lenses. The power in diopters equals the reciprocal of the focal length in metres, thus a lens whose focal length is 20 cm. has a power of 5 diopters.

Dispersion — The separation of individual colours of light by differential refraction of their wave lengths.

Displacement, Relief — The difference in the position of a point above or below the datum, with respect to the datum position of that point, owing to the perspective of an aerial photograph. Relief displacement is radial from a point on the photograph corresponding to the ground position vertically beneath the camera. In true vertical photography relief displacement is radial from the principal point of the photograph.

Distortion, Lens — An aberration affecting the position of images off the axis, caused by the fact that objects at different angular distances from the axis undergo different magnifications.

Dodging — The process of holding back light from certain areas of the sensitized paper in making a print, in order to avoid overprinting those areas. In projection printing it is accomplished by inserting an opaque medium of proper shape and size between the lens and the easel, and in contact

printing either by varying the illumination in given areas of the negative or by inserting translucent or opaque paper between the light source and the negative. Dodging may also be performed automatically by means of specially designed electronic or fluorescent printer.

Drift

1. (Air Navigation) The horizontal displacement of an aircraft, under the action of the wind, from the track it would have followed in still air.
2. (Aerial Photography) Sometimes used to indicate a special condition of crab wherein the photographer has continued to make exposures oriented to the predetermined line of flight while the aeroplane has drifted from that line.

Effective Area

For any aerial photograph that is one of a series in a flight strip, the central part of the photograph delimited by the bisectors of overlaps with adjacent photographs. On a vertical photograph, all images within the effective area have less displacement than their conjugate images on adjacent photographs.

Elevation

Vertical distance from the datum usually mean sea level, to a point or object on the earth's surface. Not to be confused with altitude, which refers to points or objects above the earth's surface.

Emulsion

A suspension of a light-sensitive silver salt, usually silver chloride or silver bromide, in a colloidal medium, usually gelatin, used for coating photographic films, plates, or paper.

Enlargement

A negative, diapositive, or print made at a larger scale than the original.

Exposure

The total quantity of light received per unit area. Exposure may be expressed as the product of illumination and exposure time in such units as meter-candle-seconds.

Eye Base

The distance and orientation of the line between centres of rotation of the eyeballs of an individual. It differs from interocular distance in the sense that it is oriented.

Factor, Filter

The amount of film exposure that must be increased to offset the reduction in light resulting from the use of a filter. A filter absorbs part of the light

passing through it; therefore, less light reaches the film. The lens diaphragm must be opened wider or the shutter longer for correct exposure of the film. A filter factor of 2 means that the normal exposure must be doubled.

Fading — The loss of part or all of an image owing to incomplete fixing or washing, etc.

Fiducial Marks — Index marks, rigidly connected with the camera lens through the camera body, which form images on the negative. The marks are adjusted so that the intersection of lines drawn between opposite fiducial marks defines the principal point.

Film — A thin, flexible transparent sheet coated with light-sensitive emulsion, for use in the camera.

Film, Infrared — Film carrying an emulsion especially sensitive to "near-infrared" and blue light. Blue light is cut out by use of a deep red filter. Used to photograph through haze, because of the penetrating power of infrared light, and in camouflage detection to distinguish between living vegetation and dead vegetation or artificial green pigment.

Film, Panchromatic — Film sensitive to wave lengths of 400 to 700 millimicrons, i.e., to the entire visible light spectrum including orange and red, in addition to those colours recorded by orthochromatic film.

Filter — A transparent material used in the optical path of a camera lens to absorb a certain portion of the spectrum and prevent its reaching the sensitized photographic film.

Focus — The point toward which rays of light converge to form an image after passing through the lens. This point of convergence usually lies on the film or plate during exposure.

Fog — A darkening of negatives or prints by a deposit of silver which does not form a part of the image. Fog tends to increase density and decrease contrast. It may be caused by exposure to unwanted light, exposure to air during development, forced development, impure chemicals, etc.

Forward Lap — See overlap.

Fusion (Stereoscopic) — That mental process which combines the two perspective images on the retinas of eyes in such a

manner as to give a mental impression of a three dimensional model.

Glossy Print — Print made on photographic paper with a shiny surface.

Grainy — Characterized by a lack of smoothness of the silver deposit, caused by clumps or groups of particles. Excessive graininess reduces quality, especially when magnified or enlarged.

Grid — A system of lines superimposed on aerial photographs, mosaics, maps, charts, and other representations of the earth's surface, in respect to which points on the ground are located.

Halation — A spreading of a photographic image beyond its proper boundaries, particularly because of reflection from the side of the film or plate support opposite to that on which the emulsion is coated. It is particularly noticed in photographs of bright objects against a darker background.

Highlights — Those portions of a subject from which the greatest amounts of light are reflected.

Horizon, Apparent — The plane of the apparent or visible junction of earth and sky.

Horizontal — In a plane which is at right angles to the plumb line or vertical.

Image — The representation of an object produced by optical or chemical means, or both.

Image, Ghost — The reflection of light from a bright subject by the elements of the lens or its mounting to form a spurious image.

Intervalometer — A timing device for automatically operating the shutter of a camera at any predetermined interval.

Isocentre — 1. The unique point common to the plane of a photograph, its principal plane, and the plane of an assumed truly vertical photograph taken from the same camera station and having an equal principal distance.
2. The point of intersection on a photograph of the principal line and the isometric parallel.
3. The point on a photograph intersected by the bisector of the angle between the plumb line and the photograph perpendicular.

The iso-centre is significant because it is the centre of radiation for displacements of imags owing to tilt.

Lens — A piece, or combination of pieces, of glass or other transparent material shaped to form an image by means of refraction.

Magazine — A container for protecting and holding film while the camera is in operation. It is usually detachable from the camera so that a new magazine or film roll may be introduced during flight.

Map — A representation in a plane surface, at an established scale, of the physical features (natural, artificial, or both) of a part or all of the earth's surface with the means of orientation indicated. A map may emphasize, generalize, or omit the representation of certain features to satisfy specific requirements. Frequently the word "map" is preceded by an adjective which explains what type of information the map is designed primarily to present.

Map, Base — A map showing certain fundamental information, copies of which are used to compile additional data of specialized nature. Often used in reference to a large-scale planimetric map compiled from aerial photographs, copies of which are used for the addition of other data derived by photogrammetric or photographic interpretation means.

Map, Contour — A topographic map which portrays relief by means of contour lines.

Map, Flight — A map on which are indicated the desired lines of flight and/or positions of exposure for the taking of aerial photographs, or the map on which are plotted, after photography, selected air stations and the tracks between them.

Map, Planimetric — A map which presents only the horizontal positions of represented features; distinguished from a topographic map by the omission of relief in measurable form. The natural features usually shown on a planimetric map include rivers, lakes, seas, mountains, valleys, marshes, and deserts. The cultural features include cities, farms, transportation routes, public utility facilities, and political and private boundaries. A planimetric map

intended for special use may present only those features which are essential for its purpose.

Mask — (1) A sheet of thin black paper, metal, or celluloid normally used to obtain white margins on a photograph.
(2) Any material used over a print or negative to obscure a part of the image.

Matte Print — Print made on photographic paper with a dull finish; more suitable for pencil or ink annotations than a glossy print.

Mosaic — An assemblage of overlapping aerial photographs whose edges have been matched to form a continuous photographic representation of a portion of the earth's surface.

Mottled — Covered with irregular spots; said of negatives, prints, or image texture.

Nadir — That point on the celestial sphere directly beneath the observer and directly opposite the zenith. Also called "nadir point."

Near Point — The nearest object to the camera which is acceptably sharp when the camera is focused for a given distance.

Negative — (1) A photographic image on film, plate, or paper, in which the tones are reversed.
(2) A film, plate or paper containing such a reversed image.

Orientation — Direction or arrangement with respect to detail. The direction in which a photograph is turned with respect to observer, map, etc. A single photo is best oriented for study when turned so that the shadows are cast toward the observer.

Over-development — The result of permitting film or paper to remain in the developer too long, resulting in excessive contrast or fog.

Over exposure — The result of too much light being permitted to act on a light-sensitive material, with either too great a lens aperture or too slow a shutter speed or both. Results in excessive image density.

Overlap — The amount by which one photograph includes the same area covered by another, customarily expressed as a percentage. Overlap between

aerial photographs in the same flight is called "forward lap"; or "end lap"; overlap between photographs in adjacent parallel flights is called "side-lap."

Overlay — 1. A transparent sheet giving information to supplement that shown on maps. When the overlay is laid over the map on which it is based, its details will supplement the map.
2. A tracing of selected details on a photograph, mosaic, or map to present the interpreted features and the pertinent detail, or to facilitate plotting.

Parallax, Absolute — In a pair of truly vertical photographs which have equal principal distances and are taken from the same flight heights, or in a pair of rectified photographs, the term denotes the algebraic difference, parallel to the air base, of the distances of the two images from their respective principal points. Also called "x-parallax."

Parallax Difference — The difference in the absolute parallaxes of two points imaged on a pair of photographs. Customarily used in determination of the difference in elevation of objects.

Parallax Wedge — A simplified stereometer for measuring object heights on stereoscopic pairs of photographs. It consists of two slightly converging rows of dots or graduated lines printed on a transparent templet which can be stereoscopically fused into a single row or line for making parallax measurements to the nearest 0.002 inch.

Pattern — In a photo image, the regularity and characteristic placement of tones or textures. Some descriptive adjectives for patterns are regular, irregular, random, concentric, radial, and rectangular.

Photograph — A picture formed by the action of light on a base material coated with a sensitized solution which is chemically treated to fix the image points at the desired density.

Point, Principal — The intersection of the extended optical axis of the camera with the ground surface or the intersection of lines joining opposite fiducial marks.

Positive — (1) A photographic image having approximately the same retention of light and shade as the original subject.

(2) A film, plate, or paper containing such a image.

Print — A photographic copy made by projection or contact printing from a photographic negative or from a transparent drawing as in blueprinting.

Print, Ratio — A print whose scale has been changed from that of the negative by photographic enlargement or reduction.

Print, Semi-Matte — A print intermediate in glossiness between a matt and a glossy print.

Processing — The operation necessary to produce negatives, diapositives, or prints from exposed film, plates or papers.

Projector — An optical instrument which throws the image of a negative or print upon a screen or other viewing surface.

Radial — A line or direction from the radial centre of a photograph to any other point on the photograph.

Reflection — The return of light from any surface.

Refraction — The bending of light rays when light passes from one transparent medium into another having different index of refraction. The angle of refraction is the angle the refracted ray makes with the line perpendicular to the surface separating the two media.

Representative Fraction (R.F.) — The relation between map or photo distance and ground distance, expressed as a fraction (1/25,000) or often as a ratio (1:25,000) (1 inch on map = 25,000 inches on ground). Also called "scale".

Resolution — The ability of the entire photographic system, including lens, exposure, processing, and other factors, to render a sharply defined image. It is expressed in terms of lines per millimeter recorded by a particular film under specified conditions.

Resolving Power — A mathematical expression of lens definition, usually stated as the maximum number of lines

per millimeter that can be resolved (that is, seen as separate lines) in the image.

Restitution — The process of determining the true positions of objects the images of which appear distorted or displaced on aerial photographs. Restitution corrects for distortion resulting from both tilt and relief displacement.

Shadow — Obscurity within the area or space from which direct rays from a source of light are excluded by an interposed opaque body.

Shutter — The mechanism of a camera which, when set in motion, permits light to reach the sensitized surface of the film or plate for a predetermined length of time.

Speed, Emulsion — A measure of the sensitivity of the emulsion. It determines the exposure required to produce the desired image.

Stereogram — A set of photographs or drawings correctly oriented and mounted for stereoscopic viewing.

Stereoscope — A binocular optical instrument for assisting the observer to view two properly oriented photographs or diagrams to obtain the mental impression of a three-dimensional model.

Stereoscopic Image — That mental impression of a three dimensional object which results from stereoscopic vision.

Stereoscopic Pair — Two photographs with sufficient overlap and consequent duplication of detail to make possible stereoscopic examination of an object or an area common to both.

Stereoscopic Vision
Stereo Vision — That application of binocular vision which enables the observer to view an object simultaneously from two different perspectives (as two photographs taken from different camera stations) to obtain the mental impression of a three-dimensional model.

Stereoscopy — The science or art which deals with three-dimensional effects and the methods by which these effects are produced.

Templet — 1. A pattern or guide used to shape, delimit, or locate an area.

2. A device used in radial triangulation to represent the aerial photograph; the templet provides a record of the directions of radials taken from the photograph.

Texture — In a photo image, the frequency of change and arrangement of tones. Some descriptive term for textures are fine, medium or coarse; and stippled or mottled.

Tilt — The angle between the optical axis of the camera and the vertical.

Tone — Each distinguishable shade variation from black to white.

BIBLIOGRAPHY

1. Abrams, Talbert. 1944. Essentials of aerial surveying and photo-interpretation. McGraw-Hill Book Company. New York, USA.
2. American Society of Photogrammetry. 1952. Manual of photogrammetry, 2nd Edition. Washington, D.C., USA.
3. _____ 1960. Manual of photographic interpretation. Washington, D.C., USA.
4. Avery Gene. 1957. Forester's guide to aerial photo-interpretation. Occas. Paper 156. Southern Forest Experiment Station. US Forest Service. New Orleans, La., USA.
5. _____ 1960. A check list for air photo inspections. Photogram. Engineer. 26: pp. 81-84.
6. _____ 1960. Identifying southern forest types on aerial photographs. Station Paper 112. Southeastern Forest Experiment Station. US Forest Service. Asheville, N.C., USA.
7. Gene and Merle P. Meyer. 1959. Volume tables for aerial timber estimating in northern Minnesota. Station Paper 78. Lake States Forest Experiment Station. US Forest Service. St. Paul, Minn., USA.
8. Avery, T.E. 1957. Forest measurements. McGraw-Hill Book Company. New York, USA.
9. _____ 1966. Forester's guide to aerial photointerpretation. Agr. handbook 308. US Department of Agriculture. Washington D.C., USA.
10. _____ 1962. Interpretation of aerial photographs. Burgess Publishing Company. Minneapolis, Minn., USA.
11. Avery, T. Eugene and Merle P. Meyer. 1962. Contracting for forest aerial photography in the United States. Station Paper 96. Lake States Forest Experiment Station. US Forest Service. St. Paul, Minn., USA.
12. Bagley, J.W. 1941. Aero-photography and aero-surveying, First Edition. McGraw-Hill Book Company. New York, USA.
13. Bernstein, David A. 1962. Use of aerial photography in unit area control management. Jour: of Forestry 60 (3): pp. 191-195.
14. Chase, Clarence D. and S. H. Spurr. 1955. Photo-interpretation aids. Misc. Report 38 (Processed). US Forest Service. Lake States Forest Experiment Station. St. Paul, Minn., USA.
15. Coleman, Charles C. 1960. Recent trends in photographic interpretation. Photogram. Engineer. 26: pp. 755-763.
16. Dixon. R. W. and W. E. Nennis, 1965. Inventory maintenance procedure for the province of Ontario, Second Edition. Ontario Department of Lands and Forests. Ontario, Canada.
17. Harman, W. E. 1953. Comments on the hotspot in wide angle photography Photogram. Engineer. 19: pp. 626.
18. John, Hugo H. and M.P. Meyer. 1961. Comparative forest aerial photo-interpretation results from variable-contrast and single-contrast paper prints. Photogram. Engineer. 27: pp. 698-763.

19. Johnson, Evert W. 1952. Timber volume determinations using aerial photographs (Processed). Alabama Poly-tech. Inst. Alabama, USA.
20. _____ 1953. Aerial photographs and the management of small forest holdings. Journal Ala. Acad. Sci. 23 and 24: pp. 55-59.
21. _____ 1954. Shadow-height computations made easier. Jour: of Forestry 52: pp. 863-864.
22. Landis, G. H. and H. A. Meyer. 1954. The accuracy of scale on aerial photographs. Jour of Forestry 52: pp. 863-864.
23. Loetsch. F. and K. E. Haller. 1964. Forest inventory. Vol. 1. BLV. Verlags-gesells- chaft Munchen Basel Wien. West Germany.
24. Lueder, Donald R. 1959. Aerial photographic interpretation principles and applications. McGraw-Hill Book Company. New York, USA.
25. Mason, Bert. 1953. The hotspot in wide-angle photographs. Photogram. Engineer. 19: pp. 619-625.
26. Meyer, Merle P. 1957. A preliminary study of the influence of photo paper characteristics upon stereoimage perception. Photogram. Engineer. 23: pp. 149-155.
27. _____ 1961. Measurement of crab and flight line overlap in aerial photos. Minnesota Forestry Note 103. Minn., USA.
28. Meyer, Merle. P. and Louis H. Trantow. 1959. A comparison of 6-inch planigon lens with conventional 8.25-inch lens aerial photography for forestry purposes. Jour: of Forestry 57: pp. 634-636.
29. _____ 1955. Photogrammetric training for the technical foresters. Photogram. Engineer. 21: pp. 746-750.
30. Moessner, Karl E. 1957. How important is relief in area estimates from dot smapling on aerial photos? Res. Paper 7. US Forest Service. Inter-mountain Forest and Range Experiment Station. Ogden, Utah, USA.
31. _____ 1960. Training handbook basic technique in forest photo-interpretation. US Forest Service. Intermountain Forest and Range Experiment Station. Ogden, Utah, USA.
32. Moessner, Karl E. and E. J. Rogers. 1957. Parallax wedge procedures in forest survey. Miscellaneous Publication 19. US Forest Service. Inter-mountain Forest and Range Experiment Station. Ogden, Utah, USA.
33. _____ 1966. Comparative usefulness of three parallax measuring instruments in the measurement and interpretation of forest stands. Photogram. Engineer. pp. 27: 705-709.
34. Ray, R. G. 1960. Aerial photographs in geological interpretation and mapping. Professional Paper 373. US Geological Survey. Washington D. C., USA.
35. Society of American Foresters. 1955. Forestry handbook. The Ronald Press. New York, USA.
36. Spurr, S. H. 1948. Aerial photographs in forestry. The Ronald Press. New York, USA.
37. _____ 1960. Photogrammetry and photo-interpretation. Second Edition. The Ronald Press Company. New York, USA.
38. Sump, Albert W. 1949. Use of aerial photographs in management palnning. US Forest Service, Region 9. Milwaukee, Wis. USA.
39. US Department of Agriculture. 1964. Identification of tree species on large scale panchromatic and color aerial photographs. Agri. handbook 261. Washington, D.C., USA.
40. US Department of Agriculture. 1966. Aerial photo-interpretation in classi-fying and mapping soils. Agri. handbook 294. Washington, D.C., USA.

41. US Forest Service. 1964. Photo-interpretation instruction for the third Wisconsin forest survey, US Forest Service. Lake States Forest Experiment Station. St. Paul, Minn., USA.
42. Wright, Marshall S. Jr. 1960. What does photogrammetric mapping really cost? Photogram. Engineer. 26: pp. 452-454.
43. Zeilinsky, V. G. 1963. Photographic interpretation of the trees pecies in Ontario. Ontario Department of Lands and Forests, Ontario, Canada.
44. _____ 1964. The practice of photo-interpretation for a forest inventory. Ontario Department of Lands and Forests. Ontario, Canada.

Other Publications by the Author

1. Working Plan for Haripur Guzara Forests (1965).
2. Survey Plan for Timber Resources Assessment in Northern West Pakistan (1969).
3. Evaluation of Forest Co-operative Societies in Hazara (1983).
4. Evaluation of Forest Co-operative Societies in Hazara (1985).
5. Supply of Timber to D.F.I.C. (PIDC) and Determination of Royalty of Timber (1986).
6. Forest Policy for NWFP (1986).
7. Forest Policies and Programme in Mountain (1988).
8. Evaluation: FAO Regional Energy Fuelwood Development Project (1989).
9. Problems and Prospects of Forestry in Pakistan (1989).
10. A Report on Grazing Rights in Forests and Open Pastures in Himalayas (1989).
11. A Case Study of Forest Harvesting Systems in Mountain Forests of Pakistan (1990).
12. Forest Management in Himalayan, Karakuram and Hindu-Kush Region of Pakistan (1990).
13. Forest Policies Programmes in Northern Region of Pakistan, (1991).
14. Review and Analysis of Forest Policies of Pakistan (1992).
15. Forest Policy, Administration and Management in Pakistan (1992).

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