CARTOGRAPHY
III
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LESSON 1
IDENTIFY AERIAL
PHOTOGRAPHIC IMAGERY

OBJECTIVE: At the end of this lesson, you will be able to identify aerial photographic imagery by using a pocket stereoscope.


CONDITIONS: You will have a pocket stereoscope, a #2 pencil, and this subcourse booklet. You will work on your own.

STANDARDS: Aerial photographic imagery must be identified by using a pocket stereoscope.

CREDIT HOURS: 2

REFERENCES: Extract of TM 5-240, Compilation and Color Separation of Topographic Maps, chapter 5, paragraphs 5-6 through 5-8.
INSTRUCTIONAL CONTENT

INTRODUCTION

As a cartographer, you are primarily concerned with the portrayal of cartographic information on topographic maps and map substitutes. This information can be classified in broad categorical groups, such as hydrography, hypsography, lines of communication, urban analysis, miscellaneous cultural features, and vegetation.

The best way to thoroughly teach you photographic interpretation would be to show you a photograph of every known type of imagery you would ever find on a photograph. This is impossible to do because the earth is constantly being changed by man and nature. It would also be impractical to assemble a volume of selected photographs dealing with photomapping.

We realize that you cannot hope to become an adequate cartographer without some help in the identification of features. This is the primary function of this lesson. After reading the lesson and the extract of TM 5-240, paragraphs 5-6 through 5-8, work through the review exercises at the end of this lesson.

PHOTOGRAPHIC INTERPRETATION

Interpretation of aerial photography is the process of determining, through the use of aerial photographs, the identity and physical characteristics of features of terrain, works of man and nature, and the extent of ground, sea or air activity. Briefly stated, photo interpretation is--

- The art of knowing what you are looking for.
- Identifying and interpreting the physical characteristics when you see them.
- Knowing the significance of these physical characteristics in the specific location.

During photo interpretation, one examines photographic images of objects for the purpose of identifying the objects and deducing their significance. Taken literally, this process may apply to anyone who sees a movie, watches television, or looks at pictures in a magazine or newspaper. Everyone is to some degree a photo interpreter. However, photo interpretation as practiced by the amateur is not to be confused with professional interpretation as performed by a cartographer. A cartographer has a solid background of training and experience. This background enables a cartographer to identify many small or subtle features of photographs which the amateur would overlook or misinterpret.
FUNDAMENTALS OF PHOTOGRAPHIC INTERPRETATION

Objects have shape, size, pattern, tone, shadow, and site characteristics that help determine the identity of their photographic images. The interpreter must consider these characteristics before it is possible to accurately identify objects on a photograph.

IMAGE CHARACTERISTICS

Shape is the configuration of an object. The general form or outline of an object determines its shape. Shape is probably the most important single factor in recognizing objects. It is also of great importance in recognizing objects from their photographic images. When seen through the stereoscope, a photographic image seems three-dimensional. This is a critical factor in identification of an image. For example, a circular figure may not be readily identified as a water tank or a petroleum, oil, and lubricants (POL) tank until it takes shape under the stereoscope.

On ground photographs and obliques, objects appear in profile, but on a vertical photograph, they appear in plan, like a blueprint. A knowledge of the characteristic appearance is best gained by comparison of the photographic image with the object on the ground or with the map symbol representing it. It is important to keep the scale of the photograph in mind when studying the shapes and sizes of objects. A light square image may represent a building on a 1:5,000-scale photograph. The same size patch on a 1:20,000-scale photograph may represent a cultivated field. A forest is irregular in shape, whereas an orchard is more or less regular; yet both contain trees. Roads and railroads are both long and narrow. Roads curve more sharply than railroads and have other roads joining at right angles.

The relative size and shape of an unknown object in relation to known objects often furnish good clues to identification. Man-made features such as buildings, railroads, and cities are usually geometric shapes with regular patterns. Natural features such as natural drainage, ocean or lake shorelines, and mountains are usually irregular. The shape of a river may tell a great deal about geology and terrain. A straight stream has a narrow valley and steep sides, while a meandering stream has a wide valley and gentle slopes. Shape is also important to the interpreter of industrial area photographs. Knowledge that buildings of a certain shape are common to the steel industry, and that buildings of a different shape are found in the oil industry, is vital information for this interpreter.
Sizes of objects will aid in object identification. A characteristic of size is the surface or volume dimension. The cartographer usually identifies objects from images that vary in size from one scale of photography to another. Therefore, the cartographer must make calculations of the actual size of the objects represented. The shape of the object is misleading at times. A simple check of the comparative size will prevent misinterpretation. When reduced, a warehouse may look like a shack.

The relative size of an object is a valuable aid in interpreting photographs. A truck on a road gives an idea of the road width. Outlying residential houses may be compared in size to warehouses. Often you can identify an object by its size in relation to other objects—for instance, a church in comparison to a house, both in the same block. A stream may be distinguished from a river by the relative amount of erosion that has taken place.

Pattern refers to the random arrangement of natural or man-made objects. “Know a man by the company he keeps,” applies to data shown on aerial photographs. Many objects can be identified by examining their surroundings. If the viewer sees a solid object sitting in the middle of a field, its shadow may be misleading and the conclusion made that the object is a house. Association and common sense also may influence a viewer in identifying an object. It is obvious that some means of entry is necessary, even into an uninhabited building. Even if a house has been deserted for some time, some evidence of a path or roadway will normally show on a photo. The dark object in question would more likely be a haystack since there is no evidence of a path or road.

Comparing the various sizes of buildings in a given area aids in determining probable usage. Commercial and industrial areas tend to contain large buildings in close proximity. Small buildings with more room around them mark the usual pattern of residential areas. In a sparsely settled area, a large building may be an isolated factory, but in a populated area it is more likely to be a school. This supposition is strengthened if some type of playfield is found in the immediate vicinity.
Water tanks can be distinguished from oil tanks by surrounding structures. One such structure is the fire protection moat that most communities require around inflammable storage facilities. See the photograph below.

The way man-made or natural objects are arranged on the ground often create distinctive patterns. These characteristic patterns, in return, help the photo interpreter to recognize the features. Some good examples of pattern are military installations, shopping centers, and housing developments.

**Tone** refers to the brilliance with which light is reflected by an object. On a black-and-white photograph, objects assume a shade of gray between the extremes of black and white. This is due entirely to the amount of light which is reflected by the object to the camera. Tone provides many helpful clues to identifying objects. The more light that is reflected by the surface of an object toward the camera, the whiter the object appears on the photograph. A surface which reflects no light toward the camera appears black on the photograph. Therefore, the tone of an object on two consecutive photographs taken at different times will vary because the reflection of rays from the sun will not be at the same angle. Because of the dominant effect of texture, the tone of objects will often appear much lighter or darker than the color would warrant. The following tone effects should be understood.

A smooth surface is a good reflector of light. Objects appear white when the camera is in that position which catches the reflected rays of the sun. However, if the light is not reflected to the camera, a smooth object appears dark. The image of smooth water, which is an example of such a surface, is sometimes light and other times dark, depending upon the angle at which the rays from the sun fall upon it.

Most natural surfaces reflect light in all directions and appear intermediate in tone because some of the reflected light filters into the camera.
All reflecting surfaces are not level, for example, the roofs and sides of houses. Some objects, regardless of the position of the sun, will reflect light and appear white.

Rough surfaces reflect light at many different angles, in varying amounts, depending upon the nature of the object. Their tone is usually an intermediate gray.

Color has the same effect also. A roof painted white or some light color appears light while a black or dark color roof may appear dark. Yet, both roofs might be smooth.

**Shadows** cast by an object show the condition in which an intervening object prevents direct sun rays from striking images on the photograph.

The shape and outline of a shadow indicates a profile view of the object casting the shadow. This may help in the identification of the object.

The objects within the shadow reflect very little light back to the camera, making them difficult to see on a photograph. An object falling within the shadow of a larger object may be partly or completely obscured. To assume the identity of the object may be dangerous. A close study of the surrounding area may help to clarify the obscured object.

**Site** refers to the environment of the object or series of objects. For example, industrial areas are usually located along rivers or railroad tracks. This is something like pattern, but on a larger scale.

Many times the surroundings of objects or the proximity of objects to others offers a clue for identification. A large building with a baseball diamond nearby might indicate a school or at least a gathering place for many people. A similar building with railroad tracks would very likely be a depot, a warehouse, or a factory. Notice the layout of a typical railroad facility in the illustration on the next page.
TYPICAL RAILROAD FACILITY

RAILROAD FACILITIES WILL HAVE MOST OF THE FEATURES SHOWN ON THIS DIAGRAM. IN SMALLER YARDS, THE RECEIVING, MARSHALLING AND DEPARTURE YARDS CAN BE COMBINED INTO A LONG MULTIPURPOSE YARD.

PASSENGER TERMINALS WILL USUALLY HAVE A PASSENGER WALKWAY OVER OR UNDER THE TRACKS. LARGER FACILITIES WILL BE COMPLETELY COVERED AND CAN BE MISTAKEN FOR MAINTENANCE FACILITIES.

TANK FARMS, FACTORIES AND WAREHOUSES ARE COMMON TO, BUT NOT NECESSARILY LOCATED AT ALL RAIL FACILITIES.

MAINTENANCE YARDS ARE USUALLY LOCATED AT ALL MAJOR YARDS. A CHARACTERISTIC OF MAINT. FACILITY IS A ROUNDHOUSE AND A TURNTABLE.
The location of an object in relation to other features is often very helpful in identifying the object. This applies to man-made and natural features. Examples of site identification are buildings near a marshalling yard, a parking lot, or a recreational center.

**UTILIZING SHADOWS IN PHOTOGRAPHIC INTERPRETATION**

All objects cast shadows when the light source is behind them. The sun is the source for the creation of aerial photographic shadows. The shadows that result reveal characteristics of the shape of an object which are vital to accurate interpretation.

The vertical image of an object shows only the top portions on a photograph. Vertical offsetting in the shape of the object will show poorly, and few clues will be provided about the underlying shape. By studying the shadows of the object, much can be learned about overall shape. For example, different species of trees can be identified by the characteristic shape of the shadows.

The shadow of an object is usually helpful in identifying features on a photograph. Looking straight down from a plane, the camera makes the top of a silo and the top of a water tower look alike. However, the shadow of the silo is a solid patch running away from the base, while the shadow of the water tank is a smaller, dark patch some distance away, perhaps with the shadows of its supports also showing.

In analyzing cultural features, the shape of structures and the general type of construction can be read from the shape of the shadows. For example, the number of spans, cable suspensions and/or abutments are often reflected in the shadow of a bridge. Structures built for specific purposes often conform to characteristic patterns. If the cartographer is familiar with the shapes of special-purpose structures as they appear on the landscape, then cataloging the probable use from the photo shadows is possible.

The relative size of objects can be estimated by an amateur and actually determined by a professional. This can be accomplished by measuring the length and width of shadows, and by scaling the sizes of images on aerial photos. Tall buildings cast long shadows, small buildings cast less pretentious ones. Adequate interpretation of size is impossible without considering the surroundings and location of the object. For example, shadows of tall buildings located in cities do not have a chance to stretch themselves upon the ground but are cramped into the narrow cracks made by streets between them. Mountains throw large shadows across the land. The size of these shadows may be great enough to nearly engulf the pattern of other features, such as trees. For accurate size determination, it is often necessary to sift the pattern of the surrounding objects from the shadows. A knowledge of relative tone supplies this filter.
Shadows may tell you the relative height of an object if there is another shadow of a familiar object nearby. If you compare the length of the shadow of a steeple with that of a telephone pole, you will have some idea of the height of the steeple. Notice the various shadows in the photograph below.

**TONÉ ANALYSIS**

Under favorable circumstances, it is possible to determine near-surface ground conditions by tone characteristics alone. However, accuracy is often limited by such factors as quality of photographs, climatic influence, and vegetation obstructions. It is always necessary to cross-check the interpretation with the help of the other major keys such as topography, drainage, and vegetation.

The method of reproduction of photographs establishes the color values. In ordinary photographic processes, various tones of gray make up the photograph. In other methods of reproduction, variation in shades of brown, blue, or other colors may be used. It is the variation in shade, rather than the basic color of the photo, that is important.

The shade or tone values do not remain constant across the span of a single photograph. If a band of soil having uniform light tones was to appear in a photograph, the portions appearing at the edges would be darker than those at the middle. This portion would still retain light tones in relation to adjacent areas.

It is evident, then, that the use of tones in the interpretation of aerial photographs should be limited to the study of relative differences of shades in an area, preferably in the central portion of stereopairs.
VALUE OF RELATIVE TONE

*Tone of vegetation.* Tonal values may aid in the discrimination of several objects. The spacing between trees and possibly the foliage produces different tones. Shadows of solid objects, like mountains, are more uniform in tone. Careful inspection of mountain shadows may unfold a lighter tonal effect that offers a clue to the presence of vegetation which at first glance seems lost in the shadows. Freshly plowed fields show up as dark patches on photos because moisture has been brought to the surface by plowing deeper into the ground. The surface of unseeded, plowed fields dries out rather rapidly. Pictures taken a short time after plowing will show a lighter toned image than newly plowed fields. Fields of growing crops will produce still other tones that are keys to interpreting the amount, density of growth, and type of crop. No amount of explanation can help you visualize these tonal values. Tonal perception can be developed only through practice. Notice the various tones in the photograph below.
**Tone of transportation surfaces.** Smooth curved roads, especially those constructed with concrete, show as light bands on photographs. Dirt and rough-surfaced roads appear much darker in tone. The dirt between railroad ties are in sharp tonal contrast to the metal rails on large-scale photographs. Airstrips, landing fields, and surfaced parking areas reflect light. Consequently, these areas are much lighter in tone than the darker ground that usually surrounds them. Tone on aerial photography can help determine various right-of-ways, such as roads, railroads, and rivers.

**Tone interpretation of water depths.** Shallow water produces a lighter tone than deep water. Sandbars, subsurface shelves, and sawyers can be spotted by lighter tones in clear water bodies. Variations of tone are lost on muddy, underdeveloped photos. A large part of success for the interpreter depends upon the quality of the prints used. All of the discussion about tone may be in vain if the photographer has not developed these tonal qualities on the print.

**CONTRAST, TEXTURE, AND RESOLUTION AS APPLIED TO AERIAL PHOTOGRAPHS**

*Contrast* is the difference between the highlights and shadows of a photograph. A good example of contrast is an open area of sand that is overcast by a shadow from a nearby object.

*Texture* is the frequency of tone change within the image; the nature of the surface that is photographed.

*Resolution* can be an important factor in photographic interpretation. The measure of the finesse or sharpness of detail visible on a photograph is said to be the resolution. Photographs that contain blurred images make the job of the cartographer more difficult. Resolution is completely dependent upon the mechanics of photography.

**AIDS TO PHOTOGRAPHIC INTERPRETATION**

Before a photograph can be studied or used for identification of features, it must be oriented for proper viewing. This consists of rotating the photograph so that the shadows point toward the viewer. This orientation places the source of light, the object, and the viewer in a natural relationship, and is necessary for proper viewing of both single photos and stereopairs.

**Stereoscopy** is the science which deals with three-dimensional viewing of photographic images. Stereovision is the ability to perceive depth, which results from the fact that each eye views the same object from a slightly different angle. The two separate views are fused in the brain and perceived as a single, three-dimensional image. An optical aid, such as the pocket stereoscope as seen in the illustration on page 12, is used to assist you in achieving stereovision on a stereopair. A stereopair is two aerial photographs which overlap each other to such a degree that two slightly different angles of the same image are recorded.
To use a stereoscope to obtain a three-dimensional view, certain procedures must be followed:

- Arrange the photographs in the sequence in which they were taken.
- Select a stereopair covering the area to be examined.
- Orient the stereopair.
- Place the stereoscope over the photographs.
- Position an object from the photo overlap area under each of the eyepieces of the stereoscope.
- With the photographs and the stereoscope in this position, a three-dimensional image should be seen.

Many methods of height determination are based on the stereoscopic view. Comparative heights of shadowless features, which are so important in many phases of photo interpretation, are almost impossible to determine without stereoscopy.

Magnification employs optical instruments to change the size ratio between the photographic image and the object. It enables the interpreter to develop, from a photographic image, characteristics which can be interpreted. Magnification is a limited tool. Although there is no theoretical limit to the amount of enlargement possible, there are many limiting factors in practical interpretation caused by distortion.
CHARACTERISTICS OF HYDROGRAPHIC FEATURES

Surface waters, in whatever form they may occur, are the hydrographic features of the earth. Streams, lakes, seas, springs, ponds, swamps, and seeps are examples of natural features. Cultural or man-made features include canals, irrigation and drainage ditches, and reservoirs. Bodies of water appear light or dark, depending on the amount of surface reflection at the time the photographs were taken. Clear water absorbs a great amount of light and consequently appears dark. Muddy waters appear gray or quite light on a photograph because dirt particles tend to reflect light.

Definite shorelines have permanent vegetation near the water, since the water does not advance or recede any appreciable distance. If the high-water mark borders on a marine cliff, the position of the shoreline may be easily established. If, on the other hand, the high-water mark borders a gradually sloping beach, the exact position of the mark is difficult to determine from an aerial photograph. Usually, two lines of slight discoloration will be seen along the beach. The inshore line is the line of wave-washed debris and is usually a little more distinct than the outer line, which is the high-water line. In areas where the force of waves breaks before reaching shore, the debris line and the high-water line will be the same. Notice the sharp and well-defined shoreline in the photograph below. There are no bud flats or gently sloping beaches. The vegetation is close to the water's edge.
**Indefinite shorelines** lack permanent vegetation near the edge of the water since the periodic advance and recession of the water prevent vegetation growth. The slope from land to water is so gradual that a small change in water level, due to tides or drought, causes the shoreline to advance and recede. An indefinite shoreline generally appears wet and is difficult to determine as shown in the photograph below.

![Indefinite Shoreline](image)

**Perennial lakes** usually have a sharp, well-defined shoreline and have a uniform color-tone appearance. Man-made lakes, in most cases, have a dam located at one end. The shorelines are very definite, with vegetation growing close to the water. This indicates that there is very little fluctuation of the water area.

**Intermittent lakes** are distinguished by the differences in color tones of the soil around the outer edges of the lake. Alternating bands of light and dark grays extend toward the dark center of the slight dip in the surface of the earth.

**Perennial streams** maintain a constant flow of water more than six months of the year. Perennial streams occur in areas of average or above average rainfall where heavy vegetation contributes to a slow and continuous runoff. Such streams are also fed by springs, lakes, melting snow, and swamps. In hilly terrain, streams are fairly straight with narrow valleys or even deep gorges, indicating a high velocity of water current. In gently sloping terrain, the streams meander and are serpentine.
Intermittent streams maintain a waterflow less than six months of the year. They are common in semiarid regions and in areas of barren, rocky, or sandy soil. These streams flow for a limited time after seasonal rains or spring thaws but are dry for the remainder of the year.

Canals are artificial or man-made watercourses used for the drainage of land, for irrigation, or for navigation by boats, barges, or ships. The banks or walls form a distinct contrast with the adjoining land area, appearing as light or dark lines on a photograph.

CHARACTERISTICS OF RAILROADS, ROADS, AND RELATED FEATURES

The transportation system of an area provides an indication of the economic and industrial significance of the area. Generally, industrial, commercial, and residential areas follow a fixed pattern as associated with the transportation system and adjacent built-up areas.

Since the building structures along transportation lines are often significant, it is imperative that all primary and representative patterns of the connecting routes be shown on the chart. In this category are mainline railroads, branch lines and spurs, rail yards, railroad stations, all highways, trails, bridges, overpasses, underpasses, causeways, tunnels, ferries, and fords.

Roads are very easy to interpret, and in most cases, appear as light lines or narrow bands. The more they are used, the lighter they appear. Improved roads show regularity in width and have a clean-cut outline. The center of each lane may appear darker, due to oil drip from cars. Unimproved or dirt roads appear light and irregular in width and have sharp turns. The photograph below shows a representative pattern of different types of roads.
**Railroads** are generally narrower than roads and appear darker. They are distinctively straight with large-radius curves. Two railroad tracks do not intersect at right angles.

**Bridges** are easily recognized by the shadows they cast. Usually, the type of bridge can be determined by a close inspection of the photograph. Details of construction of a steel railroad bridge are readily apparent in an oblique photograph.

**CHARACTERISTICS OF POPULATED PLACES AND BUILDINGS**

Populated places and buildings are easily interpreted by an inspection of the photographs. After some experience with interpretation, you will be able to identify populated areas and buildings and determine the height and surface construction material of buildings. Study the photograph below, paying particular attention to the building size and appearance. This is an oblique photograph. Notice how the combination of tilt and height, the relief, makes it possible to count the number of floors.

**CHARACTERISTICS OF MISCELLANEOUS CULTURAL FEATURES**

The display of miscellaneous cultural features serves a number of purposes on charts. These features serve as landmarks for aircraft orientation. They also furnish a large portion of the cultural background upon which a critical analysis of the area can be based.
Cultural features include mining features, power transmission lines, pipelines, dams, harbor structures, aeronautical features, and miscellaneous and landmark features such as ruins, cemeteries, forts, racetracks, stadiums, lighthouses, and missile launch sites. Power transmission lines are easily recognized by the shadow of their towers and the straight alignment of the lines. In the photograph below is a military airfield. Notice the typical military layout of the buildings. See if you can easily identify some of the aircraft on the field.

CHARACTERISTICS OF HYSOGRAPHIC FEATURES

*Hypsography* is the portrayal of relief features which reflect the differences in elevation of a portion of the earth's surface. Hysographic features include, but are not limited to, karst and lava areas, sand, cuts and fills, escarpments, and bluffs and cliffs. These features may have significant landmark value.
REVIEW EXERCISES

Now that you have worked through the instructional materials for Lesson 1, check your understanding by completing these review exercises. Try to complete all the exercises without looking back at the lesson. When you have completed as many of the exercises as you can, turn to the solutions at the end of the lesson and check your responses. If you do not understand a solution, go back and restudy the section in Lesson 1 where the information is given. Paragraph references follow each solution.

Section I

1. What is the single most important factor in recognizing objects around us?
   A. Color
   B. Shadow
   C. Shape
   D. Pattern

2. What is the random arrangement of objects called?
   A. Site
   B. Pattern
   C. Shape
   D. Photo image

3. How will a surface which reflects no light on a photograph look?
   A. White
   B. Light gray
   C. Dark gray
   D. Black

4. What is the environment of an object called?
   A. Pattern
   B. Texture
   C. Site
   D. Shape

5. How do roads constructed of concrete appear?
   A. Light bands
   B. Dark bands
   C. Large bands
   D. Small bands
6. What is the frequency of the tone change within an image called?
   A. Value
   B. Contrast
   C. Resolution
   D. Texture

7. Since clear water absorbs light, how will it appear on a photograph?
   A. White
   B. Dark
   C. Light gray
   D. Does not show

8. What is the economic and industrial significance of an area indicated by?
   A. Transportation system
   B. Agriculture
   C. Building structure
   D. Population

9. How does a photographic image seen through the stereoscope appear?
   A. Magnified
   B. Three-dimensional
   C. Light
   D. Dark

10. What tells a great deal about the geology and terrain of an area?
    A. Road construction materials
    B. The size of a river
    C. The size of the buildings
    D. The shape of a river

11. Most natural surfaces reflect light in what direction?
    A. Toward the sun
    B. Away from the sun
    C. In all directions
    D. Away from the camera

12. Shadows reveal what characteristic of an object?
    A. Size
    B. Shape
    C. Site
    D. Pattern
Section II

This section is designed to test your ability to obtain stereoscopic vision using a pocket stereoscope. Read the procedures for stereoscope use on the next page.

13. What is the object in the illustration below?
   A. A hole
   B. A pyramid

![Illustration of a hole and a pyramid]

14. What is the order of nearness to you of the lettered circles in the illustration below?
   (Closest) _____ _____ _____ _____ (Farthest)

![Illustration of lettered circles]
15. Using the illustration below, list the three lettered or numbered circles appearing in each of the three rows.

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<th>Highest</th>
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**Procedures for using a pocket stereoscope:**

Unfold the pocket stereoscope and adjust the distance between the lenses to fit your eyes. (Normal distance is 2.25 to 2.75 inches between the center of the lenses.)

Set the stereoscope over the illustration; through the center of the illustration’s “flight lines,” and parallel to the line through the center of the lenses.

While looking through the stereoscope and keeping the lines in “b” above parallel, relax your eyes. Initially you may see two images. Eventually, these should merge together revealing one, three-dimensional image.

If you do not see any relief, slowly move the lenses together or apart until the relief aspect is clearly apparent.

If you fail to get the relief effect, ask your supervisor for assistance.
Section III

This section is designed to test your ability to interpret images on area photographs. Remove figures 1 and 2 from the back of this subcourse. Using a pocket stereoscope, determine the identity of the features annotated on the aerial photographs.

16. What is the identity of feature 16?
   A. Fuel tanks
   B. Water treatment plant
   C. Silos
   D. Water towers

17. What is the identity of feature 17?
   A. Divided highway
   B. Hard surface road
   C. Railroad tracks
   D. Loose surface road

18. What is the identity of feature 18?
   A. Gravel pit
   B. Coal pile
   C. Cultivated field
   D. Lake

19. What is the identity of feature 19?
   A. Viaduct
   B. Bridge
   C. Overpass
   D. Underpass

20. What is the identity of feature 20?
   A. Trail
   B. Stream
   C. River
   D. Loose surface road

21. What is the identity of feature 21?
   A. Bridge
   B. Viaduct
   C. Overpass
   D. Underpass
22. What is the identity of feature 22?
A. Athletic field
B. Park
C. Drive-in theater
D. Parking lot

23. What is the identity of feature 23?
A. Warehouse
B. House
C. Church
D. Swimming pool

24. What is the identity of feature 24?
A. Warehouse
B. House
C. Church
D. Swimming pool

25. What is the identity of feature 25?
A. Divided highway
B. Loose surface road
C. Hard surface road
D. Railroad tracks

26. What is the identity of feature 26?
A. Divided highway
B. Railroad tracks
C. Hard surface road
D. Loose surface road

27. What is the identity of feature 27?
A. Hard surface road
B. Loose surface road
C. Divided highway
D. Railroad tracks
EXERCISE SOLUTIONS

Section I

Answers

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<td>D, Black, 5, 3</td>
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<tr>
<td>4.</td>
<td>C, Site, 6, 7</td>
</tr>
<tr>
<td>5.</td>
<td>A, Light bands, 11, 1</td>
</tr>
<tr>
<td>6.</td>
<td>D, Texture, 11, 4</td>
</tr>
<tr>
<td>7.</td>
<td>B, Dark, 13, 1</td>
</tr>
<tr>
<td>8.</td>
<td>A, Transportation system, 15, 3</td>
</tr>
<tr>
<td>9.</td>
<td>B, Three-dimensional, 11, 7</td>
</tr>
<tr>
<td>10.</td>
<td>D, The shape of a river, 3, 4</td>
</tr>
<tr>
<td>11.</td>
<td>C, In all directions, 5, 5</td>
</tr>
<tr>
<td>12.</td>
<td>B, Shape, 8, 2</td>
</tr>
</tbody>
</table>

Section II

13. B, A Pyramid

14. (Closest) 2, 1, 4, 3 (Farthest)

15. | Lowest | Middle | Highest |
    |--------|--------|---------|
    | Row I  | U      | M       | 4       |
    | Row II | S      | T       | C       |
    | Row III | A     | G       | L       |

Section III

Answers

<table>
<thead>
<tr>
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<tr>
<td>16.</td>
<td>A, Fuel tanks, 16, 4</td>
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<tr>
<td>17.</td>
<td>C, Railroad tracks, 16, 1</td>
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<tr>
<td>18.</td>
<td>D, Lake, 14, 2</td>
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<tr>
<td>19.</td>
<td>C, Overpass, 17, 1</td>
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<tr>
<td>20.</td>
<td>B, Stream, 14, 4</td>
</tr>
<tr>
<td>21.</td>
<td>A, Bridge, 17, 1</td>
</tr>
<tr>
<td>22.</td>
<td>D, Parking lot, 17, 1</td>
</tr>
<tr>
<td>23.</td>
<td>A, Warehouse, 16, 3</td>
</tr>
<tr>
<td>24.</td>
<td>B, House, 16, 3</td>
</tr>
<tr>
<td>25.</td>
<td>A, Divided highway, 15, 5</td>
</tr>
<tr>
<td>26.</td>
<td>C, Hard surface road, 15, 5</td>
</tr>
<tr>
<td>27.</td>
<td>B, Loose surface road, 15, 5</td>
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</table>
LESSON 2
PREPARE AERIAL PHOTOGRAPHIC LINE INDEX

OBJECTIVE: At the end of this lesson you will be able to perform the methods and procedures used in preparing an aerial photographic line index.


CONDITIONS: You will have a 5-H pencil, paper, calculator (optional), and this subcourse booklet, and you will work on your own.

STANDARDS: An aerial photographic line index must be accurately prepared.

CREDIT HOURS: 1
INSTRUCTIONAL CONTENT

INTRODUCTION

Aerial photography is used extensively by the Armed Forces. It is used for photo interpretation and map and chart compilation. It is so widely used that the Armed Forces are accumulating aerial negatives at the rate of over five million a year. To make maximum use of aerial photography, you must be able to determine what type of photography best fits your needs. To aid you in this, the indexing systems were developed. The Defense Intelligence Agency (DIA) is the custodian of all aerial photography flown by the Armed Forces.

PHOTO INDEX

A unit producing photography is required to forward the negatives and a photo index of the photography to DIA. The photo index is on an acetate overlay and consists of a plot of the photography and textual information pertaining to the photographs. Textual information might include organization, focal length, altitude, remarks, plot scale/map, date, time, snow cover, percentage of cloud cover, classification, any additional security information, the preparer of the textual information and the quality of the photograph. The photo index submitted to DIA is used for filing and retrieving negatives. Quite often an index to cover an entire project is desired in order to readily position specific photos within the project area. When this is the case, we either use a photo index or a photographic line index.

A photo index is plotted by comparing photographs to a map sheet. The flight diagram, pilot’s record and log, and plotting templet are aids in constructing this index. All plotted photographs are in their true position relative to the map utilized and all labeling and textual information must be accurate. The photo index is generally preferred because of the amount of information it contains. Preparation of a photo index requires more time and equipment than needed for a photographic line index. Therefore, procedures for preparation of a photographic line index will be given in this lesson.

PHOTOGRAPHIC LINE INDEX

The photo index is generally preferred because of the amount of information it contains, but its assembly requires excessive time and equipment. A photographic line index is a plot of photography keyed to a map sheet. The flight diagram, pilot’s record and log, and a plotting templet are aids in constructing the photographic line index. All plotted photographs are in their true position relative to the map utilized, and all labeling and textual information are accurate.
This flight line index contains lines showing the location of the flight.

This flight line index shows photographs plotted to scale. Each photograph or every fifth photograph is plotted to scale along the flight line.
In the flight line index below, photographs are center-plotted. In this index the center of each photograph is plotted on the flight line using a small square or circle as the symbol.
A templet is used for plotting the area covered by a photograph. See illustration.

The templet is made of two transparent plastic right angles with a 5-inch scale divided into tenths on each right angle. The right angles are assembled into a square by two screw bolts in long slots on each side of the angles. By moving the templet to the right angles along the grooves, any size square or rectangle can be formed from 1/10 to 5 inches.

The size of the templet is the average map dimension covered by the photographs to be indexed. It is found by multiplying the length of the photograph by the denominator of the photograph scale, and dividing this by the scale of the map. This will give you the width of one side of the templet.

If the photo plotter templet is not available, a templet can be constructed from acetate paper.

Plotted photograph areas are inked or penciled in, as shown in the illustration below.
PLOTTING THE INDEX

No matter what type of index is being plotted, it is constructed by reviewing the film or prints after the mission is flow. The flight diagram and pilot’s record and log are only aids when plotting the index.

The following procedures are used in plotting the various types of indexes:

\[
\text{Templet size} = \frac{\text{Photo Size} \times \text{Denominator Photo Scale}}{\text{Denominator Map Scale}}
\]

\[
\text{MD} = \frac{(\text{PD}) \times (\text{DPS})}{\text{DMS}}
\]

**Example:**
- Size of photo: 9” x 9”
- Scale of photo: 1:20,000
- Scale of map: 1:250,000

\[
9 \times 20,000 \times \frac{1}{250,000} = \frac{180,000}{250,000} = 0.72 \text{ inch}
\]

Templet size is 0.72” x 0.72”

The templet is placed on the map and adjusted until it covers the area of the photograph as accurately as possible by matching detail points along the edge. The outline of the photograph is then traced.

Photographs that are plotted have a number that is divisible by “5” (5-10-15-20). You should insure that each photograph plotted matches the same area on the base map.

The last photograph in the fight line is plotted in the same manner.

If a holiday (blank space) occurs within the fight line, plot the photograph in front and behind the holiday, regardless of the photograph number (5-10-11-14-15), 12 and 13 would be open areas.
Lines are then drawn connecting the plotted photographs. See the illustration below.

Exposure numbers are shown on each plotted photograph in the drawing below. Lines are omitted where holidays are indicated. An index or plot shows the relationship of each exposure to the others and to the project as a whole.

A line index is usually keyed to a 1:250,000 scale map of the area, containing plotted lines showing the location and identification of the flight. Each picture, with its designating number, is plotted as a small square to scale. For most purposes, the exposure numbers shown at the beginning and end of each flight line are sufficient. If a break occurs in the flight, the exposure numbers at each break are shown on the chart. Gaps in photographic coverage are indicated graphically and clearly labeled.
DATA INFORMATION BLOCK

If the textual information is not included on the overlay, a data information block is prepared. It may be
detailed, like the list below, or as brief as required by the project instructions. It will always include the
first four items on this list:

- Collecting organization and service
- Mission information
- Imagery date
- Map source and scale
- Sensor information (focal length and type)
- Imagery scale
- Average aircraft altitude
- Imagery quality
- Security classification

When indexing, the marginal data requirements vary. An index generally contains the project name,
number and location, the taking organization, date of the photography, negative numbers, focal length,
type of camera used, scale of the photography, scale of the photo index, and a diagram showing the
relationship to adjacent photo indexes.

INDEXING SYSTEMS

Topographic units and others using aerial photography need a system to show the relationship between
the photos they are using. Various systems have been developed to index newly-acquired photography
in order to make it available when needed at a later date. Aerial photographic line index is a system that
serves this purpose. Indexes are designed to aid in filing negatives, and to show the relationship of
photographs within a project. In this lesson you have learned how to prepare the required photographic
line index.
REVIEW EXERCISES

Now that you have been through Lesson 2, check your understanding by completing these review exercises. Try to complete all the exercises without looking back at the lesson. When you have completed as many of the exercises as you can, turn to the solutions at the end of the lesson and check your responses. If you do not understand a solution, go back and restudy the section in the lesson where the information is given. Paragraph references follow each solution.

1. What is a photographic line index used for?
   A. Plot the preflight mission
   B. Locate map source
   C. Identify control points
   D. Locate the flight

2. When are photographic indexes prepared?
   A. At 1:5,000 scale
   B. After the mission is flown
   C. During the photo mission
   D. Before the mission is flown

3. If you index a flight of photographs with the following information, what is the templet size?
   Size of photo 9 x 9
   Scale of photo 1:20,000
   Scale of map 1:250,000
   A. 0.68
   B. 0.72
   C. 1.58
   D. 1.72

4. What geographical area does a properly constructed templet used in constructing a line index represent?
   A. Photo mission
   B. Flight line
   C. Map sheet
   D. Photograph
5. Photographs that are plotted have a photograph number. What is that number divisible by?
   A. Two
   B. Three
   C. Four
   D. Five
   E. Six

6. A line index is usually keyed to a scaled map of the area at what ratio?
   A. 1:15,000
   B. 1:25,000
   C. 1:50,000
   D. 1:250,000

7. What is a data information block prepared on?
   A. Overlay
   B. Map
   C. Reproducibles
   D. Photograph
## Lesson Exercise Response Sheet

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<thead>
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<th>Student Name</th>
<th>SSN</th>
<th>Date</th>
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</thead>
<tbody>
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<td>Current MOS</td>
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<tr>
<td>Subcourse No.</td>
<td>Lesson No.</td>
<td></td>
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<tr>
<td>Date Received</td>
<td>Date Completed</td>
<td></td>
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</table>

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
## EXERCISE SOLUTIONS

<table>
<thead>
<tr>
<th>Answers</th>
<th>Page, Paragraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. D, Locate the flight</td>
<td>30, 4</td>
</tr>
<tr>
<td>2. B, After the mission is flown</td>
<td>34, 1</td>
</tr>
<tr>
<td>3. B, 0.72</td>
<td>33, 2</td>
</tr>
<tr>
<td>4. D, Photograph</td>
<td>33, 1</td>
</tr>
<tr>
<td>5. D, Five</td>
<td>34, 2</td>
</tr>
<tr>
<td>6. D, 1:250,000</td>
<td>35, 3</td>
</tr>
<tr>
<td>7. A, Overlay</td>
<td>36, 1</td>
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</tbody>
</table>
LESSON 3
SUPPLEMENTARY CONTROL

OBJECTIVE: At the end of this lesson you will know two methods of establishing supplementary control by using the radial line triangulation method and the Analytical Photogrammetric Positioning System (APPS).


CONDITIONS: You will have this subcourse booklet. You will work on your own.

STANDARDS: Accurately establish supplementary control.

CREDIT HOURS: 2

REFERENCES: Extract of TM 5-240, Compilation and Color Separation of Topographic Maps, chapter 6, paragraphs 6-1 through 6-6, and 6-8. EN5302.
INSTRUCTIONAL CONTENT

INTRODUCTION

Control is a system of marking the position and elevation of an object. The four types of control points used in the construction of the compilation base are geodetic, picture, principal, and pass. Locating photogrammetric control with respect to geodetic control is known as EXTENSION OF CONTROL. The purpose of photogrammetric control is to increase the density of control. With this increased control, photographic detail can be accurately plotted on a compilation base. This increased control can also be used as a base for laying controlled or semi-controlled mosaics and for map revision. The extension of control for a controlled or semi-controlled mosaic is done by the use of ground control, principal points, picture points, and pass points. The first method we will discuss is radial line triangulation. Another method is the slotted templet method. Finally, the Analytical Photogrammetric Positioning System (APPS) method of photogrammetric control method is discussed.

CONTROL POINTS

In this lesson we will discuss the different types of control points and the criteria for classifying and describing control data. The four types of control points used in the construction of compilation are geodetic, picture, principal, and pass.

There are two basic types of geodetic control points, horizontal and vertical. These control points are established in the field by survey methods, are permanently marked with their elevation, and known simply as ground control. They serve as the base framework of the entire system, for positioning features on the new maps, and constructing controlled mosaics. The geodetic ground control points are symbolized with a dot centered inside a triangle.

Picture points are supplementary horizontal or vertical points that are photo identifiable on an aerial photograph. These points are established by field survey parties and identified on the photograph. The surveyor correlates the geodetic ground control to the picture points. Once the two points have been correlated, a point is then symbolized on the photograph as ground control. Picture points are used when there is a lack of ground controls in the project area.
The principal point is the exact geometric center of an aerial photograph. This center point is normally found by connecting opposite fiducial marks. See the illustration below.

If fiducial marks are not visible, the principal point can be located by drawing diagonal lines from the corners, as in the illustration below.
Pass points serve as a basis for tying photographs together and bridging between the picture points and ground control. Usually, picture points are not located in sufficient density or proper arrangement to insure adequate control. Additional control, pass points, must then be selected and marked on the photographs. These points must be features identifiable on the photographs but they are not surveyed or known ground control. There should be six pass points on a photograph. Each pass point should be along the side-lap edges of the photograph. When the pass points are located on the photograph, each point will fall on six photographs. This will enable the cartographer to extend the control from photograph to photograph and from flight line to flight line throughout the project areas. See the illustration below.

**RADIAL LINE TRIANGULATION CONTROL**

Radial line triangulation is a method in which direction lines from the center of each overlapping photograph are used to extend horizontal control by the successive intersection and resection of these direction lines. This principle is illustrated below. We use a strip of six consecutive photographs. There are four ground control points (TOM, DON, JOHN, BILL).
Steps in Performing Radial Line Triangulation:

Step 1: Plot all the ground control points on all the photographs that they fall on. Locate all the principal points (1 through 6). The principal points will be labeled with the photo number.

Step 2: Transfer the principal points on all the photographs to preceding and succeeding photographs. This is done with a pocket stereoscope so that each photograph has three consecutive principal points (on end photographs, there are only two). The pocket stereoscope is used because principal points are rarely located on a readily identifiable point of detail. It is extremely important to use care in transferring the principal points to insure that their locations are exactly the same. Now that all the principal points have been transferred, draw a line that joins these points to make up the approximate flight line for the strip. See the illustration below.

Step 3: Select the pass points. Choose well-defined points about 1/2 to 2 inches from the edge of the photographs. The pass points should be on a line that is approximately parallel with the flight line and perpendicular to the principal points as in the illustration below.
Step 4: Transfer pass points to adjoining photographs using the pocket stereoscope. The same pass point will fall on three photographs. Since the points are selected within 1 1/2 to 2 inches of the edge, they will also fall in the common side-lap area. The same point will fall on three photographs at the next flight line. See the illustration below.

Step 5: Construct the radial lines. The radial lines are drawn from the principal point on each photograph through each pass point and from the principal point to each ground control point. These lines should be 1 1/2 to 2 inches in length where they pass through the pass point or ground control point. See the illustration below.
Step 6: Make the radial line templets for each photograph. Lay tracing mylar over each photograph and trace the position of the principal point, ground control points, and all pass points. Label each point on the template. At this time, there are no set standards for labeling points. The only points that have a set name or number are the ground control points. The principal points have the number of the photograph on which they originate. Ground control points will be symbolized by a triangle with a dot in the center that marks the control station. Principal points are usually marked by a cross line ( ). Use a circle to mark the pass points and label them with a numbering system. The numbering system should make it easy for you to follow the pass points through the flight lines. Label each template with the number of the photograph for which it is made. See the illustration below.

Step 7: Plot all ground control on the map base (grid) to the common scale of the photographs. The ground control will be plotted using the Universal Transverse Mercator (UTM) coordinates given on the DA Form 1959 (Station Description Card). After this is done you can start assembling the radial line plot with the first template that has the most ground control points. Move the template over the map base until the ground control points precisely intersect the same location on the base. Tape the template to the base. See the illustration below. The next template in the flight line will be positioned with the common flight line superimposed. The template is moved along the flight line until the radial lines of the ground control precisely intersect the control on the base map. Tape this template to the base.
Step 8: Add the remaining templets in the flight line in order. After the first line is completed, start on the next adjacent line. Begin with the templent that has the most ground control. Remember all the radial lines from pass points and those from ground control should intersect precisely at the same location. All pass points in the interior of the project should be on at least six photographs and will be represented by a six-way cross of radial lines. If a ground control point on a templent does not match there will have to be some adjustment throughout that line. See the illustration below.

Control point JOHN does not align with the radial line for point JOHN on the templent. To aid in adjusting point JOHN on the templent, label this point JOHN'. Now place a sheet of tracing paper over the entire flight line, and mark all the principal points. Draw the flight line plus point JOHN and the location at JOHN' as in the illustration below.
Draw a line approximately parallel to the flight line. Then draw a line connecting control point JOHN and JOHN' as in this illustration.

Mark the location of the principal points on the parallel flight line and label them 1a, 2a, 3a, 4a, 5a, and 6a. This is done by laying off the distance from 1-2, 2-3, 3-4, 4-5, and 5-6. See the illustration below.

Draw a line parallel to JOHN - JOHN' from principal point 6a on the parallel flight line. See the illustration below.

Measure the distance between JOHN and JOHN' and lay out this distance on the parallel line from 6a. This point will be marked 6b as in the illustration below.
Draw a line from principal point 1a to principal point 6b as in this illustration. This will be the adjustment line.

Draw lines parallel to 6a - 6b from all the remaining principal points on the parallel flight line to the adjustment line as in this illustration. These points are labeled 2b to 5b. This will give you the distance of the adjustment that has to be made on the principal flight line.

To adjust the primary principal point (1 through 6), draw a line parallel to JOHN - JOHN' from each primary principal point. Then measure the distance from 2a to 2b, 3a to 3b, 4a to 4b, 5a to 5b, 6a to 6b and transfer the distance as in this illustration. Label these points A2 through A6.
After the new principal points, A2 through A6, have been plotted and the new flight line drawn, adjust the templets to their new locations. See the illustration below.

Step 9: After all the templets have been relocated to their corrected positions and taped to the base, use a pin vise to transfer all the principal points and pass points to the base. This is done by pushing the pin vise through the principal points and the intersection of the pass points. Now, you are ready to transfer the information from the photographs to the map for revision or for making templets to rectify a controlled mosaic.

SLOTTED TEMPLET CONTROL

Another method of control extension is the slotted templet method. The slotted templet method is based on the same theory of control extension as radial line triangulation. Both locate points in their true position by a network of triangles, but hand drafting in the radial line method is replaced in the slotted templet method by a mechanical aid called a slotted templet. Read the extract of TM 5-240, paragraph 6-8, on how to use this equipment.
ANALYTICAL PHOTOGRAMMETRIC
POSITIONING SYSTEM (APPS) CONTROL

Another method for establishing supplementary control is by using the Analytical Photogrammetric Positioning System (APPS). To use the APPS, select and mark the pass point control on the aerial photographs the same way as discussed in the extract of TM 5-240. The pass point must be in side-lap and overlap areas of an identifiable feature such as a building, tree line, or road intersection. Compare the corresponding data base photos and measure the points with the APPS. The UTM coordinates obtained from the APPS for those points can then be plotted on the compilation base. This final product would be a control network which is more accurate and established faster than in radial line triangulation.

APPS is a combination of instruments which has a variety of applications. It combines a programmable calculator, an optical device, in this case an optical mechanical scanner, and the equipment necessary to connect or interface these instruments. This equipment, along with the Point Positioning Data Base (PPDB), allow the APPS to find the geographic and UTM coordinates and the elevation of points on photography. The APPS uses photogrammetry which is the science of making precise measurements from photographs. The illustration below depicts an APPS.
The PPDB consists of a series of photographs and a magnetic tape cartridge. The mathematical relationships of points on the photographs are known and stored on the magnetic tape for use by the calculator. The PPDB also contains aids designed to assist the operator in locating a point to measure. The aids include a map of the coverage area of the data base called a photocoverage index or user's guide. Using the index, the operator can select the stereopair of photographs which contains the point to be measured. See the illustration below.

What allows measurements to be made is a data grid on the optical mechanical scanner baseplate which interacts with a coil on the photo carriage? The data grid is a series of wires which are one thousandth of an inch apart. The calculator can measure which grid wire is closest to the coil by means of an encoder. The encoder converts the position of the coil over the data grid to electrical signals the calculator can understand.

The photo carriage has X and Y parallax adjustment knobs which allow a pair of photographs to be brought into stereoview. The measuring mark, as seen through the eyepieces, can then designate the point to be measured.
When adjusting the optics on the APPS, a standard must be established. The standard is a sharply focused, single field of view with measuring marks merged in the center of the field of view: To accomplish this, the following controls will need to be adjusted: interpupillary distance control (IPD), large mirror adjustment, small mirror adjustment, and the eyepiece focus. Care should be taken not to touch the surface-coated mirrors. See the illustration below.

The user's guide, which is included in the PPDB, discusses relative and absolute accuracy of the data base. Relative refers to accuracy from point to point within the data base. Absolute accuracy is tied to the earth's surface. Accuracy will vary from data base to data base. There are both horizontal and vertical accuracy statements in each data base.
Accuracy, both relative and absolute, is stated in percentage of error. A probability of error of 50% would mean that 50% of the readings obtained would be within the stated accuracy and 50% would not. See the illustration below. If we took six readings, then three would fall within the stated accuracy (Distance A) and three would not (Distance B).

If absolute accuracy is 13 meters, probability is 90%, and ten readings are taken, then you might plot readings as shown in the diagram below. Nine of the readings are within the 13 meters and one is not. The 90% is an average and really only applies when a large number of readings are taken. When tasked to read a point with the APPS, you reply with the coordinates and say that there is a 90% probability that the coordinates you read are within 13 meters of absolute location. Remember that the accuracy will vary as stated in the PPDB user's guide.
Follow the procedures for operation closely until you develop a clear understanding of the APPS. A standard to be considered here is to enter figures into the calculator with absolute accuracy.

An example of numbers that you will be asked to enter are numbers corresponding to grid lines. These are called reseau intersection identification (ID) numbers. They are read opposite of UTM coordinates. Reseau intersections are read up and right. See the illustration below. The intersection circled would be 1614. The first intersection on each photo is entered via the keyboard following ones computed by the calculator. Failure to enter these numbers properly will result in inaccurate readings.
When entering reseau intersection ID numbers into the APPS, the four intersections selected should surround the point or points of interest and form a square. This is called indexing and it will be done on the right photograph and then the left photograph.

When indexing, it is important to put the measuring mark exactly on the reseau intersection. Operating the foot switch inputs the ID number of the intersection into the calculator.

After indexing each photograph, you will press the foot switch once again and the calculator will print the sigma (measurement of error) in microns. This is a measurement of how well you indexed the reseau intersections for acceptable sigmas. See the illustration below.

**ACCEPTABLE SIGMAS**

1. **LESS THAN 25 MICRONS.**

2. **LESS THAN 60 MICRONS.** IF Y DISTANCE OF MEASURED SQUARE IS GREATER THAN 8 CM.
Using the X and Y parallax adjustment knobs, merge the right photographic image to the left photographic image. The merged measuring marks should be placed on the ground and within the area defined by the reseau indexing procedure. It may help to blink your eyes alternately. In some APPS applications, it may be necessary to use the X parallax adjustment knob to put the measuring mark on the ground. Doing this depends on your ability to see in stereo. Failure to do this properly will result in inaccurate elevation readings. In most cases elevation will not be required for plotting control. However, elevation readings can be used for other cartographic applications.

In order to read a point, an ID number must be entered into the calculator when the display reads “P. T. Option.” Any number of one or larger is an acceptable ID number. It is suggested that a number different from those used to designate your geodetic control points be used to avoid confusion.

When you are reading a point, you should place the measuring mark on the feature to be measured and press the foot switch. The calculator will then print the UTM coordinates. These coordinates can then be used as pass points. The coordinates should be plotted on the base using bow dividers and an invar scale. This is the same as plotting geodetic control. See Lesson 6 in EN05302 or FM 5-81C 1/2, Task 051-257-1205, Plot Geodetic Control. The base with plotted geodetic and pass points can now be used for constructing a semi-controlled mosaic or as a map compilation base.
REVIEW EXERCISES

Now that you have worked through the instructional materials for Lesson 3, check your understanding by completing these review exercises. Try to complete all the exercises without looking back at the lesson. When you have completed as many of the exercises as you can, turn to the solutions at the end of the lesson and check your responses. If you do not understand a solution, go back and restudy the section in the lesson where the information is given. Paragraph references follow each solution.

1. What is a supplementary point established by field survey?
   A. Reference mark
   B. Pass point
   C. Geodetic control point
   D. Picture point

2. What is a point that is identifiable on a photograph but not surveyed on the ground?
   A. Picture point
   B. Geodetic control point
   C. Reference mark
   D. Pass point

3. What is found when you connect the fiducial marks on an aerial photograph or draw diagonal lines between the corners of a photograph?
   A. Pass point
   B. Control point
   C. Principal point
   D. Picture point
4. What is the length, in inches, of the radial line drawn through the pass and ground control points?
   A. 1 - 1 1/2
   B. 1 - 2
   C. 1 1/2 - 2
   D. 1 3/4 - 2 1/4

5. How should points on a photograph be transferred to the next photograph?
   A. By using an engineer scale
   B. By using a pocket stereoscope
   C. By using a reflecting projector
   D. By using an autofocus rectifier

6. What does the line drawn from a principal point to a transferred principal point on a photograph indicate?
   A. Radial line
   B. Diagonal line
   C. Flight line
   D. Plumb line

7. What are the first points plotted on photographs?
   A. Ground control points
   B. Pass points
   C. Transferred principal points
   D. Principal points
8. What are the second points plotted on photographs?
   A. **Ground control points**
   B. Pass points
   C. Transferred principal points
   D. Principal points

9. What are the lines drawn from the principal point to the ground control point?
   A. Parallel to the flight line
   B. Radiate from the center
   C. Perpendicular to the principal points
   D. Form a triangle with the principal point

10. What is another method for extension of control?
    A. Reflecting projector
    B. Pocket stereoscope
    C. Slotted templet
    D. Autofocus rectifier

11. After radial line triangulation is finished and all points have been transferred to the base, what is the base ready for?
    A. Map revision
    B. Uncontrolled mosaic
    C. Stereo compilation
    D. Rectification
12. See the diagram on page 67. On how many photographs does point A fall?
   A. Three
   B. Four
   C. Five
   D. Six

13. See the diagram on page 67. Does point B fulfill the requirements for a pass point?
   A. Yes, it falls on three photos.
   B. No, it falls on three photos.
   C. Yes, it falls on two photos.
   D. No, it falls on two photos.
Note: The following questions pertain to the APPS.

14. When indexing you must put the measuring mark exactly on the reseau intersection and operate the foot switch. How many reseau intersections surrounding the point of interest must be used for this purpose?
   A. Three
   B. Four
   C. Five
   D. Six

15. How is accuracy determined for the APPS?
   A. It must be 10 meters or less.
   B. It must be 15 meters.
   C. It is stated on the photograph.
   D. It is stated in the data base.

16. Refer to the illustration below. When adjusting the optics, these controls should be manipulated so the measuring marks appear focused and merged in the center of the field of view.

   Match the letter to the name of the adjustment
   ___________ Interpupillary Distance Control
   ___________ Large mirror adjustment
   ___________ Small mirror adjustment
   ___________ Eyepiece focus
17. What is an acceptable sigma, in microns, when Y distance is less than 8 centimeters?
   A. 16.393
   B. 26.837
   C. 52.314
   D. 80.321

18. What is an acceptable sigma, in microns, when Y distance is greater than 8 centimeters?
   A. 48.623
   B. 61.091
   C. 68.681
   D. 82.062

19. Refer to the illustration below. What would the reseau ID number be for the intersection labeled “A”?
   A. 1219
   B. 1320
   C. 2013
   D. 2113
20. Refer to the illustration on page 69. What would the reseau ID number be for the intersection labeled “B”?
A. 1217
B. 1318
   C. 1712
D. 1813
### LESSON EXERCISE RESPONSE SHEET

Student Name ___________________________  SSN ______________________  Date

Organization ___________________________  Current MOS

Subcourse No. ___________________________  Lesson No.

Date Received ___________________________  Date Completed

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## EXERCISE SOLUTIONS

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<td>4. C, 1 1/2-2</td>
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<td>9. B, Radiate from the center</td>
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<td>10. A, Slotted templet</td>
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<td>12. D, Six</td>
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<td>14. B, Four</td>
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<td>15. D, It is stated in the data base</td>
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<td>16. C, Interpupillary Distance Adjustment</td>
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<td>B, Small mirror adjustment</td>
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<td>A, Eye piece focus</td>
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</tr>
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<td>17. A, 16.393</td>
<td>60, 3</td>
</tr>
<tr>
<td>18. A, 48.623</td>
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<td>20. D, 1813</td>
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PAGES 75 THROUGH 100
ARE EXTRACTS FROM TM 5-240
AND ARE PROVIDED AS A SEPARATE PDF DOCUMENT
Extract of:
TM 5-240, Compilation and
Color Separation of Topographic Maps,

Chapters 5 and 6.
CHAPTER 5
AERIAL PHOTOGRAPHY

5–1. Introduction
The single factor that did most to revolutionize the science of cartography was the advent of aerial photography. The aerial photograph furnishes, more completely than any other means, the information needed to prepare a map. The vertical aerial photograph approaches the ideal for mapping purposes because it registers all objects and features, not obscured or screened, in their proper perspective relation to one another. In areas free from trees, clouds and cloud shadows, a good vertical photograph will provide the compiler with an interpretable image of most of the tangible features to be mapped.

5–2. Cartographic Uses of Aerial Photography
Apart from its obvious military value for reconnaissance and intelligence purposes, aerial photography is used in many ways in the actual preparation of maps and map-related products.

a. The most basic cartographic application of aerial photography is a primary source for stereophotogrammetric compilation of topographic maps, employing instruments such as the multiplex or the high precision military stereoplotters. Such photography is carefully planned to meet the specific needs of the project, as described in TM 5–243. For a detailed discussion of the use of these instruments, refer to TM 5–239 and TM 5–244.

b. Another common use of aerial photos is in the production of photomosaics, and photomap products derived from photomosaics, such as the pictomap. The procurement of aerial photography for these purposes is usually as carefully planned as for photogrammetric compilation, with some modifications to meet the requirements for mosaicking. For example, the forward overlap and sidelap are usually greater for mosaic photography, since accurate stereo projection is not needed. Instead, an attempt is made to prepare as much of the mosaic as possible from the relatively distortion-free centers of the photos. Under combat conditions, mosaics are frequently prepared as expedient map substitutes from the best available photography, which may be cartographic, reconnaissance, or any other photography which will satisfy the requirement. The preparation of photomosaics and photomap products is discussed in chapter 9.

c. Because it can be obtained so quickly, aerial photography is an ideal source of up-to-date information which can be used to revise existing maps. Almost all such revision is made from photographs. While vertical photography provides the best source of information for photo revision, information can also be extracted from the various kinds of oblique and composite photography commonly used for reconnaissance purposes. Chapter 7 discusses the uses of aerial photography in the revision or the nonphotogrammetric compilation of maps.

d. Aerial photography is also widely used to record various data obtained by field surveyors or classifiers. Control stations are frequently photoidentified and pinpricked on photo prints in the

![Figure 5–1. Relationship of vertical photograph to ground.](image)

Extract 3
field; these can be used for many purposes other than the original stereo compilation. Photography which is field-annotated with feature identifications and classifications is invaluable both for original compilations and for revisions.

5–3. Types of Aerial Photography Used in Mapping

There are two major types of aerial photography in common use by military topographic units, the vertical and the oblique. Photography from multiple camera installations combining the two types is also used.

a. Vertical. A vertical photograph is an aerial photograph taken with the axis of the camera being maintained as closely as possible to a truly vertical position with the resultant photograph lying approximately in a horizontal plane (fig. 5–1). An example of a vertical photograph is shown in figure 5–2. Compared to oblique photos, the vertical photograph covers a relatively small area, which is square or rectangular in shape. The view of the ground is an unfamiliar one, and re-
The horizon is not visible. If the vertical photograph is taken over flat terrain, measured distances and directions may approach the accuracy of a line map.

b. Low Oblique. A photograph taken with the camera axis intentionally tilted so that it does not include the apparent horizon (fig. 5–3). Except for high altitude photography, this provides the user with a more familiar view of the ground, comparable to that seen from the top of a hill. Relief is usually apparent, but distorted, and the horizon is not visible. The low oblique photo covers more ground area than a vertical, but considerably less than a high oblique taken at the same altitude. The ground area covered has the shape of a trapezoid, although the photo itself is square or rectangular. Because the scale is not constant, distances cannot be measured, nor can azimuths be determined, since parallel lines on the ground are not parallel on the low oblique photo. It should be noted that the term “low” refers to the angle of the camera axis from the vertical, and not to the altitude of the taking camera. A low oblique photo is shown in figure 5–4.

c. High Oblique. A photograph taken with the camera axis intentionally tilted so as to include the apparent horizon (fig. 5–5). It covers a much larger area, trapezoidal in shape, than either the low oblique or the vertical photograph, but all of the area is not usable. The horizon is always visible in a high oblique, and the view of the terrain varies from the familiar to the unfamiliar, depending on the altitude of the taking camera. Like the low oblique, neither distance nor azimuths can be measured. High oblique photographs are not normally used for large and medium-scale mapping, except when no other coverage is available. A high oblique photograph is shown in figure 5–6.

d. Multiple Lens. Multiple lens photography consists of composite photographs taken with a camera having two or more lenses or by an assembly of two or more cameras (fig. 5–7). The photographs are combinations of two, four, or eight obliques around a vertical. The obliques are rectified to permit assembly as verticals on a common plane. Figure 5–8 illustrates a 9-lens composite photograph.

e. Convergent Low Oblique (Split Photography). In this type of photography, stereoscopic coverage is achieved by using two intentionally-tilted cameras, or two separate lenses angled within one camera, to take two simultaneous, intentionally-tilted photographs at each photographic station. The photograph taken by the forward-tilted camera at one station forms the stereo pair with the photograph taken by the aft-tilted camera at the next station (fig. 5–9). The tilt is usually along the line of flight, although for reconnaissance purposes, or when special mapping problems exist, the cameras may be tilted at right angles to the line of flight. Each pair of simultaneous photographs overlap each other about one inch, but overlap the adjacent photograph nearly 100 percent. The amount of tilt depends on the focal length of the cameras, flight altitude, and terrain. The overlap is generally sufficient for the nadir points to appear on both photographs. The cameras or lenses must be rigidly coupled together to preserve their angular relationship and their shutters must be precisely synchronized to insure simultaneous exposures.

5–4. Geometric Characteristics of Aerial Photography

a. The aerial photograph is a perspective view of the terrain, whereas a map of the same area presents an orthographic view. This means simply that an aerial photograph presents the terrain as it appears from a single vertical viewpoint, whereas the map presents detail as though each point on the map were viewed from directly above (fig. 5–10). Consequently, each feature is in its correct horizontal position on the map, but radial
displacements and variations in scale can cause varying degrees of positional error on the photo. To make maximum use of aerial photography in map compilation or revision, it is necessary to convert the perspective view of the photography to the orthographic view of the map. Subsequent chapters of this manual present some of the techniques for achieving this conversion. The following descriptions of some of the more critical elements of an aerial photograph must be clearly understood before these techniques can be applied.

(1) Focal plane. The plane perpendicular to the optical axis of the camera, on which the photographic image is focused. During the exposure period this plane is occupied by the film (negative); therefore, it is sometimes referred to as the film plane.

(2) Focal length. The distance measured
along the optical axis from the rear nodal point of the lens to the focal plane of the camera, when the camera is focused at infinity. Since an aerial camera is only rarely focused at any distance other than infinity, focal length can be simply defined as the distance from the focal plane to the camera lens as measured along the optical axis.

(3) Altitude. Simply defined, it is the distance of the camera lens above the datum plane (usually sea level) as measured along the plumb line. In most photomapping problems it is symbolized in equations by a capital "H". It is also sometimes referred to as flying height.

(4) Height. The vertical distance of the camera lens above the terrain as measured along the plumb line. The height of the camera and its focal length are used to find the scale of a vertical photograph:

\[
\text{Scale} = \frac{\text{Focal length}}{\text{height above terrain}}
\]

(5) Elevation. The vertical distance of the terrain above the datum, usually sea level, commonly symbolized in equations by a lower case "h". When the altitude of the plane (H) and the elevation of the terrain (h) are known, the scale of the photo is found by the formula:
(10) **Plumb point.** The point at which the plumb line intersects the ground. The plumb point is always located on the ground and not on the photograph itself.

(11) **Nadir point.** The point at which a vertical line through the perspective center of the camera lens pierces the plane of the photograph. The vertical line is the plumb line which identifies the plumb point of the photograph.

(12) **Tilt angle.** On a tilted photograph the optical axis and the plumb line do not coincide. They assume two different positions intersecting at the center of the camera lens. The angle formed by these two intersecting lines is known as the tilt angle. It is the amount the camera is tilted from the true vertical, or stated another way, it is the amount the focal plane is tilted away from a plane parallel to the datum.

(13) **Isocenter.** The radial center for all distortion caused by tilt. It is located on the photograph one-half the distance between the principal point and the nadir point in angular measurement (not linear). On a tilted photograph the optical axis and the plumb line form the tilt angle. If a line is drawn from the center of the camera lens to the focal plane, bisecting the tilt angle, its point of intersection with the focal plane locates the isocenter. On a true vertical photograph the principal point, nadir point, and isocenter coincide.

(14) **Principal line.** Simply defined it is a straight line on a tilted photograph connecting the principal point, nadir point and isocenter.

(15) **Isoline.** A line representing the intersection of the plane of a vertical photograph with the plane of an overlapping oblique photograph. If the vertical photograph were tilt-free, the isoline would be the isometric parallel of the oblique photograph.

b. Tilt has a direct effect on the geometric characteristics of an aerial photograph, and the resulting relationships are illustrated in figure 5–11. Tilt in photography is the result of pitch and roll of the aircraft or unstabilized camera mounts. When photographs are intentionally tilted, as in convergent low oblique coverage, the amount of tilt is known and rectification procedures are simplified. The amount and direction of the tilt must be determined before the photograph can be rectified. If the amount of tilt is less than 3° from the vertical, it can usually be disregarded and the photograph treated as vertical.

### 5–5. Scale Determination

a. **Scale of Vertical Photograph.** There are two
basic methods of determining the approximate scale of a vertical aerial photograph. One is to relate the measured distance between two objects on the photo to the true distance between the same objects on the ground. The other method is based on the relationship between the focal length of the camera and the height above the ground of the camera at the instant of exposure. The ground distance-photo distance method can be applied in several ways.

(1) Photo distance to ground distance. If the distance between two points on the photograph (PD) is measured, and the distance between the same two points is measured on the ground (GD), the equation \( \frac{x}{GD} = PD \), when expressed in the same unit of measure, will give us the approximate scale. The longer the measurement, the more accurate the result. Also, the measurement should pass through or near the principal point of the photograph.

Extract 9
Example: \[
\frac{1}{x} = \frac{4 \text{ inches (PD)}}{6000 \text{ feet (GD)}} = \frac{4''}{72,000''} = \frac{1}{18,000}
\]

(2) Object of known dimension. When an object of known dimensions, such as a football field, can be identified and measured on the photo, the known ground dimension is used as the GD value in the formula in (1) above. The accuracy of this method depends on the accuracy of the photo measurement, and the location of the object with respect to the principal point of the photograph. Results are not reliable for very small scale photography because of the difficulty of making accurate measurements.

(3) Photo distance to map distance. If two points can be identified both on the photo and on a map of known scale, the photo scale can be determined. The formula can be expressed as

\[
\frac{1}{x} = \frac{\text{PD}}{\text{MD} \text{ (map scale denom.)}}
\]

If the photo distance measures 5”, the map distance, 3”, and the map scale is 50,000, the formula would be

\[
\frac{1}{x} = \frac{5''}{3''(50,000)} = \frac{1}{30,000}
\]

approximate scale of photo.

(4) Focal length to height of camera. When the focal length of the camera (f) is known, the flight altitude above sea level of the aircraft (H) is recorded from the altimeter reading, and the average elevation of the terrain (h) can be determined, the approximate scale can be obtained by the formula

\[
\frac{f}{H - h} = \text{scale}
\]

For example, if the focal length is 6 inches, the altitude of the aircraft, 19,000 feet and the average terrain elevation, 1000 feet, approximate scale =

\[
\frac{6''}{19000' - 1000'} = \frac{5'}{18,000'} = \frac{1}{36,000}
\]

b. Determination of Scale on a Tilted Photo-

Figure 5-10. Orthographic (map) and perspective (photo) views of the terrain.
Figure 5-11. Effect of camera tilt.
graph. Although the scale of a tilted photograph changes in the direction of tilt throughout the photograph, the scale at any particular point can be determined if the tilt angle is known, and the principal line and the isocenter are located. The scale may be considered true along the isocline (axis of tilt); it is smaller on the side that is tilted upward, and larger on the side that is tilted downward. To determine the scale at any image point, the following formula is used:

\[
\text{scale} = \frac{f - y \sin t}{H - h},
\]

where “t” is the tilt angle, “y” is distance of the image point from the isocenter measured in the direction of tilt (along the principal line), “f” is the focal length of the camera, and H-h is the height above the ground.

c. Determination of Area (scope) of a Photograph. The area covered by an aerial photograph is usually expressed in square miles. It is easily obtained when the scale of the photo has been determined by using the common formula for finding the area of a rectangle: length times width equals area. To find the length of the photo in miles, multiply its length in inches by the scale denominator and divide by the number of inches in a mile (63,360). Repeat for the width, then multiply the two figures together to obtain the area in square miles. For example, for a 9” x 9” photo, at a scale of 1:20,000:

\[
\begin{align*}
\text{length} &= \frac{9 \times 20,000}{63,360} = 2.84 \text{ miles} \\
\text{width} &= \frac{9 \times 20,000}{63,360} = 2.84 \text{ miles} \\
\text{Area} &= 2.84 \times 2.84 = 8.0656 \text{ square miles}
\end{align*}
\]

5–6. Orientation of Photographs

Before a photograph can be studied or used for identification of features, it must be oriented for proper viewing. This consists of rotating the photograph so that the shadows point toward the viewer. This orientation places the source of light, the object, and the viewer in a natural relationship, and is necessary for proper viewing of both single photos and stereo pairs.

5–7. Image Identification

Objects have certain characteristics that help determine the identity of their photographic images and which the interpreter must consider before he can accurately identify the objects. These characteristics are shape, size, pattern, shadow, site, and tone.

a. Shape. Shape is probably the most important single factor in recognizing the objects around us. It is also of great importance in recognizing objects from their photographic images. Manmade features usually are regular in form, or have straight or smoothly-curved lines. Examples of these are buildings, highways, and railroads. Natural features, such as streams, shorelines, or wooded areas, are generally irregular in shape.

b. Size. The size of unknown objects on a photograph as determined from the scale of the photograph or a comparison with known objects of known size aids in their identification. Both the relative and the absolute sizes are important. For example, in a built-up area, the smaller buildings are usually dwellings and the larger buildings, commercial or community buildings.

c. Pattern. The way objects—manmade or natural—are arranged on the ground often creates distinctive patterns. These characteristic patterns, in turn, help the photo interpreter to recognize the features. Some good examples of pattern are military posts, ammunition dumps, and housing developments. The arrangement of trees in an orchard contrasts sharply with that of natural vegetation.

d. Shadow. The shadow of an object often provides the only clue in determining its identity. Viewed from directly above, water towers, smoke stacks, power line towers, and similar tall structures appear as circles or dots. Their shadows, however, reveal their characteristic outlines, as though viewed from the side, and help to establish their identities.

e. Site. The locations of certain objects with relation to other features can identify many photo images not easily recognized by themselves. Factories or warehouses are usually beside a railroad or railroad siding. Schools may be identified by their adjacent athletic fields. A water tower next to a railroad station and a silo next to a barn would be difficult to distinguish from each other were it not for the nearby railroad tracks or cultivated fields.

f. Tone (or Texture). Of the many different types of photographic film in use today, the film used for most aerial photography, except for special purposes, is panchromatic film. Panchromatic film is sensitive to all the colors of the spectrum; it registers them as shades of gray, ranging from
white to black. This lighter or darker gray shade of features on aerial photographs is known as the tone. The tone is also dependent on the roughness, or texture, of the features; a paved highway has a smooth texture and will produce an even tone on the photograph, while a recently plowed field or a marsh has a rough, choppy texture and will result in a rough or grainy tone. It is also important to remember that similar features may have different tones on different photographs, depending on the reflection of sunlight. For example, a river or body of water will appear light if it is reflecting sunlight directly toward the camera, but will appear dark otherwise. Its texture may be smooth or rough depending on the surface of the water itself. As long as the variables are kept in mind, tone and texture may be used to great advantage in interpreting aerial photographs.

5–8. Stereossopy and Stereovision

a. Stereossopy is the science which deals with three-dimensional effects achieved by the use of binocular vision for observation of a pair of overlapping photographs. Stereossion, which is the ability to perceive depth, results from the fact that each eye views the same object from a slightly different angle; the two simultaneous, slightly different views are fused in the brain and perceived as a single three-dimensional image. This phenomenon is applied in the study of aerial photography by using stereo-pairs, or two aerial photographs which overlap each other to such a degree that two slightly different angular views of the same photo images are recorded. When the two photographs are viewed, one with each eye, the illusion of depth is created. Usually, an optical aid, such as the packet stereoscope, is required to assist the eyes in achieving stereoscopic vision (fig. 5–12).

b. The identification of photo images is greatly facilitated by the three-dimensional view afforded by stereoscopic viewing. For example, a circular object may not be readily identified as a tank until it takes shape under the stereoscope. In addition, the relief of the terrain, which is not apparent on a single vertical photo, can be perceived and measured with the aid of proper stereoscopic instruments.

c. To use a stereoscope to obtain a three-dimensional view, certain procedures must be followed.

(1) Arrange the photographs in the sequence in which they were taken. This is done by laying out the photographs in numerical sequence and having the marginal information on each photograph pointing in the direction of flight. The marginal information on properly tilted photographs is always on the side of the photograph that was the forward direction in which the aircraft was moving when the pictures were taken.

(2) Select the stereo pair covering the area to be examined. A stereo pair consists of two overlapping aerial photographs used to see three dimensions.

(3) Orient the stereo pair so that both photo numbers are on the same side and the shadows fall toward the viewer. Overlap the photos so that the detail is continuous. This procedure avoids an "inverted" or "pseudoscopic" effect which occurs when the two photos are interchanged so that the left-hand photo becomes the right. The inverted phenomenon is the exact opposite of the stereoscopic effect. Hills appear to be depressions, and valleys appear to be ridges.

(4) Place the stereoscope over the photographs so that the left lens is over the left photograph and the right lens is over the right photograph.

(5) Separate the photographs, along the line of flight, until a piece of detail appearing in the overlap area of the left photograph is directly under the left lens and the same piece of detail on the right photograph is directly under the right lens.

(6) With the photographs and stereoscope in this position, a three-dimensional image should be seen. The hills appear to rise and the valleys to sink so that there is the impression of being in an aircraft looking down at the ground.

d. The distance which the photographs must be separated varies with the individual viewer. The
space between the viewer's pupils and his visual acuity both have an effect on the way he views stereoscopically. The lens of the stereoscope must be set at the proper distance for the viewer, usually about 2 1/2 inches apart. The correct separation of the photos is then achieved by trial and error. An easy method of separating the photos consists of placing the index finger of the right hand on a prominent image in the overlap area of the right photograph and the index finger of the left hand on the corresponding image of the left photograph. Look into the stereoscope to see the two index fingers separately, then shift the two photographs parallel to the flight line until the index fingers appear to be superimposed. Withdraw the fingers and observe the image. If necessary, adjust the photos slightly to bring the image into a clear stereoscopic view.
CHAPTER 6
CONTROL EXTENSION AND ADJUSTMENT

Section 1. INTRODUCTION

6-1. Control as Used in Compilation
In order to compile any map, the compiler must be able to position the detail he has extracted from map sources and photographs in its correct relationship to other detail and to the map projection and grid. The means by which this is accomplished is called "control", which may be defined as the system or network of points on the surface of the earth whose positions are either established, or derived from other established points, and which may be used as reference to position map detail.

6-2. Types of Control
There are several criteria for classifying and describing control data, such as order of accuracy, or method of surveying (para 4-6), but for purposes of this chapter, control is categorized and discussed according to its application in the compilation process. Control as used in compilation falls into three general types.

a. Geodetic Control Points. The basic types of horizontal and vertical control furnished as source material are described in paragraph 3-3. These control points, established in the field by surveying methods which take into account the size and curvature of the earth, are permanently marked and known as geodetic control points, or simply, ground control. They serve as the framework upon which is based the entire system for positioning features on the new map or photo mosaic. If map sources only are being used, all symbolized and verified geodetic control points, together with the graticule or grid plotted on the map source, are usually sufficient for positioning all compiled detail. When the source consists of aerial photography, however, it becomes necessary to photo-identify any control used. In most cases, fieldsurveyed geodetic control points are not used for the absolute orientation of the photography because they are seldom photo-identifiable. Such horizontal control is always plotted on the compilation base sheet by its grid coordinates, however, since it must be symbolized on the final map whether or not it is used to position detail. Permanently marked horizontal geodetic control points are symbolized with a triangle, properly labeled with its elevation, if known.

b. Picture Points. When aerial photography is used as the source for map detail, supplementary horizontal and vertical control points which are photo-identifiable are established in the field by survey parties and identified on the photography. These are called picture points, and these points, along with the geodetic control serve as the basic (ground) control for the project. Picture points are established as part of a carefully planned photogrammetric project, and are selected to provide the needed control for stereotriangulation. This basic control in conjunction with the pass points established by photogrammetric triangulation methods is used in positioning the photography.

c. Pass Points. Usually, picture points are not located in sufficient density or proper arrangement to insure adequate control of the photographs to the compilation base. Additional supplemental control points, called pass points, must therefore be selected and marked on the photographs by the compiler. These points must have features identifiable on the photographs but they are not surveyed and marked on the ground. Because the picture points may be several photographs apart, the pass points serve as a basis for tying the photographs together and bridging between the picture points.

6-3. Geodetic Control Base
To provide a compilation base upon which to establish the intermediate network of photogrammetric control points, it is necessary to plot the geodetic control on a working base containing a

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grid and projection. This geodetic ground control is plotted on either an opaque or a transparent base. Choice of material is left to the compiler, but it must have good dimensional qualities. Polyester base plastic sheeting having one matte surface makes a desirable transparent medium. Universal Transverse Mercator (UTM) grid coordinates are usually furnished for the plotting of each point (para 4–6). All points must be correctly labeled with their designation. The monumented horizontal control points are marked with red equilateral triangles approximately 7.5 mm high and geodetic control picture points are marked with red squares approximately 7.5 mm to a side, with the pinpricked control point centered in the triangle or square (fig. 6–1). Sometimes crossed guide lines are used to indicate the location of the pin prick. The name of the control station is lettered in red ink beneath the triangle or square and may be in an identifying code referring it back to the trig lists. Radial line extension of control is not affected by the vertical positions

Figure 6–1. Geodetic control plotted on base compilation.
or elevations of images; therefore, only horizontal control is required for any of the methods using radial line procedures.

6–4. Planning New Ground Control
Horizontal control is most advantageous when control lines are run at right angles to the lines of flight of the photographs. The interval between control lines depends upon ground conditions and the desired accuracy of the map. In military mapping, extension of control can be performed satisfactorily when control exists as far apart as 18 or 19 photographs. At least two horizontal control points must be located at both ends of each strip of photographs. These points must be spaced as far apart as possible within the initial or final pair of photographs to form a strong starting and finishing base. More than two points per strip give a stronger base. Where vertical control is needed to place contours upon a planimetric base, it should be planned with the horizontal control. TM 5–243 gives details of flight planning.

Section II. RADIAL LINE EXTENSION OF CONTROL

6–5. Purpose
The purpose of locating photogrammetric control points with respect to ground control is known as extension of control. Its purpose is to increase the density of control to position each photograph or stereo model from which photogaphic detail may be accurately plotted on a compilation base. It is also used as a base for laying controlled and semi-controlled mosaics. After the pass points and picture points have been located in their true relative positions, they can be adjusted to the scale chosen for the compilation or mosaic.

6–6. Methods
The extension of control may be performed by graphical methods, slotted templet method, stereo-templet method, or by multiplex triangulation.

a. Graphical methods use standard photographic prints, and correct for relief displacement by the principle of radial line intersection. Since the graphical methods assume tilt to be negligible, they are not as accurate as the stereophotogrammetric methods. Mechanical methods of accomplishing the graphical extension and adjustment of control have been devised, such as the slotted templet method which is described in paragraph 6–8, and the metal arm templet, a variation of the slotted templet, described in paragraph 6–9.

b. The stereo-templet method differs from the other techniques of radial triangulation in that the stereo-templet is representative of the horizontal plot of a stereoscopic model rather than a single photograph. A stereo-templet is a composite slotted templet designed for use in conjunction with stereoscopic plotting instruments. The function of the stereo-templet is to maintain the scale relationship between any and all points plotted from a single model while allowing for the enlargement or reduction of the overall scale of the templet. Stereo-templets are adjusted to the desired common scale when the templets are assembled to satisfy horizontal control positions. Further information on stereo-templet triangulation is contained in TM 5–244.

c. The purpose of the multiplex triangulation method is similar to that of radial line triangulation—to establish the true positions of a series of image points between bands of ground control in order to create a system of control points which will insure the position accuracy of all topographic features plotted within them. In the multiplex system, horizontal and vertical bridging are done simultaneously, whereas radial line triangulation is only horizontal bridging. The extension of control with the multiplex involves the proper orienting, scaling, and horizontalizing of one or more models in which suitable control information is available; and the use of additional projected images to form a continuous strip of stereoscopic models. Refer to TM 5–244 for a detailed discussion of multiplex triangulation.

6–7. Principles of Radial Line Triangulation

a. Vertical Photographs. The radial line method is based on the principle of resection and intersection used by surveyors. In a photograph, relief and tilt both cause displacement of the photographic images from their true map positions. Tilt displacement radiates from the isocenter; relief displacement radiates from the nadir point. However, if a photograph is perfectly vertical, these radial points theoretically coincide with the principal point, or center of the photograph, which can then be used as the radial point for all displacements. In actual practice, if the tilt is under 3° and the ground relief does not exceed 10 percent of the flight altitude, the principal point is
used as the radial center. These conditions are usually met by aerial photography planned for cartographic purposes. If a line is drawn from the principal point through the displaced image of an objective, the true position of the objective will lie somewhere on that line, although the exact point is not known (fig. 6–2). When two overlapping photographs are oriented so that the principal point on each coincides with its position on the other, then the intersection of the two radial lines through the two images of an objective establishes the true position of that objective with respect to the principal points (2, fig. 6–2). By orientation of the first pair of overlapping photographs to any desired scale, the relative positions of image points appearing on them can be established for the purpose of establishing the relative positions of image points on succeeding photographs. For example, figure 6–3 shows a set of photographs oriented to each other by radial line triangulation. Rays D₁ and C₁ radiate from the principal point “1” of the first photograph and rays D₂ and C₂ from point “2”, the principal point of the second photograph. Now if the second and third photographs are overlapped so that the principal point on each coincides with its position on the other, then rays D₃ and C₃, radiating from point “3” should intersect the other two sets of rays in common points. The points E and F are established, and are used in the same manner to continue the orientation of subsequent photographs until additional ground control is reached. This process of control extension is referred to as radial line triangulation.

b. Tilted Photographs. The radial line system is feasible in truly vertical photographs regardless of the amount of relief. However, in tilted photographs lines drawn through image points contain their true positions only when drawn radially from the isocenter and when there is no ground relief. Before measurements can be made and positions determined on tilted photographs, they must be rectified, that is, brought into a position equivalent to that of a vertical photograph. Spe-

Figure 6–2. Location of image point through intersection of radials on a pair of photographs.

Figure 6–3. Establishment of positions by radial-line triangulation.
cial rectifying printers can be used for this purpose, or the adjustments can be made by graphical or mathematical methods. TM 30-245 describes several graphical and mathematical procedures for determining tilt and making measurements on oblique photographs.

6-8. Slotted Templet Method of Control Extension

a. Introduction. The slotted templet method is based on the same theory of control extension as the radial line strip method. Both locate points in their true positions by a network of triangles, but most of the hand drafting in the radial line strip method is replaced in the slotted templet method by mechanical aids, called templats.

b. Applications. In the slotted templet method, a templet is substituted for each photograph (figs. 6-4 and 6-5). All points are transferred from the photographs to the templats, and a slot is cut through each point, radial from the principal points. These templats are then assembled by placing studs in the slots and placing the centers over their transferred positions on the adjacent templats; the use of a slot rather than a single hole allows the mass of templats to be expanded or compressed to fit the fixed control points of the compilation base. This method locates the pass points between flights in their proper relative position by 2-ray intersections, and the principal points by resection from these pass points. When the control stations on the templet are placed over the control stations plotted on the compilation base, the pass points and principal points are in their proper location at the scale of the projection.

c. Advantages. The slotted templet method is better suited to large areas, since the procedure is readily subdivided into steps that can be done at the same time by different groups or individuals.

d. Preparation of Photographs.

(1) The first step in preparing the photographs is to locate the principal point on each print. This point is located at the intersection of fine lines drawn from opposite collimating or fiducial marks, and should be marked with a black circle 7.5 mm in diameter and labeled with the photograph number (fig. 6-5).

(2) Under a stereoscope this point is transferred to the succeeding and the preceding photographs so that on each photograph, there are three consecutive principal points (on end photographs, there are only two). The lines joining these points make up the approximate flight line. The principal point is rarely located on a readily identified pinpoint of detail. Consequently, extreme care must be used when transferring points so that the transferred point is in exactly the same location. (Note that because of drift the transferred principal point may not lie on one of the fiducial lines.)

(3) Except when the principal point is located precisely on a recognizable pinpoint of detail, the stereoscope is necessary for transferring principal points. The two photographs are laid side by side in line for stereoscopic viewing. The stereoscope is placed in position so that the principal point marked on the first photograph is in the field of view; this mark will then appear to be on the second photograph. If the photographs are properly aligned, the point where the mark appears on the second photograph is the location of the transferred principal point of the first photograph. This point on the second photograph is pricked lightly with a pin or needle and marked as described in (4) below. If there is an easily-identified point no more than 3 mm from a principal point which cannot be precisely identified, it may be substituted for the principal point and used as the radial center.

(4) Principal points or substitute principal points are marked in ink by black circles 7.5 mm in diameter and numbered with its corresponding exposure number. Marking is usually done with ink and a drop compass or grease pencil.

(5) In addition to the principal point, at least two additional points called pass points are selected. These provide the necessary additional control for accurate orientation of the photographs and plotting of detail. Pass points (sometimes called wing points or radial-control points) must be clearly defined points of detail, positively identifiable on all photos on which they appear, and which fall in the small overlap area common to three consecutive photos of a flight. They are se-
Figure 6-5. Ideal arrangement of control points on the photographs and appearance of corresponding templates.
locked in the overlap area so that they also fall on three photos of the adjacent flight, if any. They are usually chosen near the center of the overlap area and are aligned, when possible, with their respective principal points. The first point is selected on the middle photograph of three overlapping photographs. The other two photographs are examined to insure that this point is identifiable on them as well, and if more than one flight is used, the three adjacent photographs of the next flight are also examined. After a point has been identified on the three overlapping photographs of each flight, it is transferred and marked. At least three pass points should appear on each side of the photograph in the overlap area between the flights (fig. 6-5). The technician should, if possible, select pass points whose elevations are as near as possible to the elevation of the principal point. This helps to reduce tilt error to a minimum. Points located at lower elevations (in valleys) are preferable to those located on hilltops or peaks.

(6) Pass points are transferred in the same way as principal points. Take special care in transferring all points, because an error introduced in this step will delay the compilation later on and may carry through to the finished map. Each pass point is prickled lightly with a fine needle and marked by a red circle 7.5 mm in diameter.

(7) A pass point normally falls on three photographs of each flight, and if selected in the overlapping area of an adjacent flight it falls on six photographs. Because of crab, drift, or offset photography, however, it is not always possible to select a point falling on six photographs. This requires selection of an additional pass point on the photograph on which the pass point did not fall. This additional pass point should fall on at least five photographs; it will not fall on the diagonally opposite photograph of the adjacent flight because the photographs are offset and there is no area common to all six (fig. 6-6). Each additional pass point is marked with a red circle 7.5 mm in diameter and labeled in the same manner as (6) above.

(8) Picture points are also identified on the strips of photography. Each picture point is transferred, with the aid of a stereoscope, from the photographs on which it was identified in the field to all photographs on which it appears. Each point is located on the photograph and prickled lightly with a pin held vertically to avoid offsetting the mark. The point is marked with a red square 7.5 mm on a side. The triangle should be approximately centered about the point, with the name or number of the control point lettered in red. This includes any monumented geodetic control points which can be positively identified on the photographs.

A-PASS POINT

B-ADDITIONAL PASS POINT

PHOTO 1 IS DIAGONALLY OPPOSITE TO PHOTO 7: NEITHER CONTAINS BOTH A AND B

Figure 6-6. Selection of additional pass point.

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e. Preparation of Templets.

(1) The templets may be made of any of several different materials, such as heavy plastic and bristol board. The tempt may be rigid to keep it from buckling when the mass of templets is assembled and scaled. Cut the tempt material to have a margin of about 1 inch (25 mm) around the photographs to allow for points that fall near the edges of the photographs.

(2) Each tempt is representative of a single photograph and is marked directly from the photograph. Attach the photograph over the tempt by small pieces of masking tape. This will hold it firmly in place while the points are being transferred. With the photograph and tempt fastened together, transfer all marked points to the tempt by pushing a fine needle through the points on the photograph. Place the photograph and tempt on a flat surface, and keep the needle perpendicular while transferring the points. One end of the photograph can be freed and the transferred points marked for identification. Label the center point, transferred centers, and ground control stations to facilitate identification when laying the templets (figs. 6-4 and 6-5).

(3) The templets marked as in (2) above are now ready for slotting. Punch through the center point of the tempt by orienting the point under the center point of cutter and depressing the handle slowly but firmly (fig. 6-7).

(4) Next, slot the pass points and ground control points. Orient the tempt in the mechanical slottter by placing the punched center hole on the centering stud of the slottter. This centering stud moves back and forth in a long groove which is directly in line with the slottter die. This movement allows the die to reach all points on the tempt except those within about 1.5 inches (38 mm) of the center. The tempt itself can be rotated about this stud to bring the pass or control point directly under the punch. Cut the slot by depressing the cutter handle so that the centering pin is directly over the point, then depress the handle fully.

(5) The mechanical slottter cuts slots for all points outside a radius of approximately 1.5 inches (38 mm) from the center point. Any points falling within this radius are slotted by a second method. With the center stud in place in the tempt, mount a radial line rule on the center stud and draw a line from the center to the point to be slotted, extending it 2 or 3 inches (50 or 75 mm) beyond this point. Punch an auxiliary hole for the centering stud along this radial line at such a distance from the point as to bring it within range of the slottter. With this hole punched, cut the slot in the same way as for all other points; take care not to cut any part of the original center hole.

(6) When using the slottter, the handle should not be depressed too rapidly, but should be pressed down firmly and evenly. This enables the punch to “set” before punching through and eliminates any chance of its catching on the side of the die.

(7) With the slottting completed, trim the templets to eliminate excess tempt material which may interfere with slots of adjacent tempt points (fig. 6-4).

f. Slotted Templet Laydown.

(1) Fasten the ground control sheet to a large wooden board. With the control plotted on the compilation base, place control pins running through a tempt stud into exact coincidence with the primary control points plotted on the base. By using the stud as a guide, these pins may be firmly driven into the base material in their proper coordinate positions and imbedded deeply enough so that there will be no possibility of the stud changing its position when the adjustment of the tempt takes place.

(2) The assembly can be started from any single picture and with any flight, although it is preferable to start with the flight strip near the middle having the most ground control. This is desirable because the accumlated error is less when started from a central flight than when started from an edge flight. Beginning at a ground control point, a tempt is placed with the fixed stud on the compilation base inserted through the slot for that control point on the tempt. Slide additional floating studs under the tempt through the center hole and the remaining
slots. Place the next templet overlapping the first so that the slots to all control points fit all the corresponding studs placed under the first templet. Superimpose additional temples in the same way, usually proceeding first along a line of ground control points and then outward from the temples already fitted.

(3) As the templet assemblage reaches other ground control points, they may fall correctly upon the corresponding points already plotted on the base. In that case, pin the control stud in its position and add subsequent temples. Quite often, however, when many temples have been employed in bridging from the last control points, the fit is not exact. There is a slight give or play among the temples which can be worked gradually in the direction necessary to bring the temples into agreement with the plotted point. Absolutely no force or pressure should be used beyond a gentle agitation of the temples and a taking up of new play, which will be very small but enough to permit the temples to be fitted to all control points.

(4) Occasionally a single templet fails to fit over those already placed and does not fall smoothly into position. Investigation usually shows that one of the pass points has been incorrectly transferred from adjoining photographs or carelessly plotted on the templet, or that an error has been made in cutting the slot. The mistake must be rectified and a new templet cut.

g. Marking Control Points. With the temples laid and control studs through all the points, a fairly rigid mass of temples should result (fig. 6-8). The points found by this method can now be transferred to the manuscript by pricking through the stud with a pin having a close tolerance to the centered hole in the stud. Then lift the temples singly and circle the pricked points on the compilation base, in black lead pencil; label all points for easy identification.

6-9. Metal Arm Templets
Metal arm temples, also called radial arm or spider temples, represent a modification of the slotted templet method. The radials are here represented by pre-cut slots in thin metal arms of various lengths which are bolted together at the center of radiation. Some advantages of the metal arm temples are that they eliminate the tendency of studs to dig into the comparatively softer material of the bristol board temples; the metal temples can be dismantled after use and reused, whereas the cardboard templet can be used only once; and the control base is visible between the arms of the assembly so that necessary adjustments can more readily be determined. To prevent corrosion of the metal temples, special stainless steel templet sets have been developed.

a. Preparation of Photographs and Templets. Photographs are prepared in a way similar to that previously described for cardboard temples.

(1) Identify the principal point, control stations, transferred principal points and a minimum of six pass points on each photograph. Draw azimuth lines through all points radiating from the principal point.

(2) Mount the photograph on a suitable mounting board and insert a pin through a templet stud and through each control point, pass point, and photo center (fig. 6-9). Place the specially designed hexagonal bolt over the central stud. Select metal arms of such length that when the last hole at one end is placed over the photo
and washer on top of the arms with the double-hex wrench to maintain proper orientation of the radial arms. The templet is marked for identification and orientation with the photograph, and then lifted off the control pins ready for the templet assembly.

A. Assembly and Orientation of Templets. Assembly of the templets is the same as for the slotted templets of paragraph 6–8. Figure 6–11 shows a metal arm templet assembly.

Section III. CONTROL OF MOSAICS

6–10. Controlled Mosaics

Controlled mosaics are laid to ground control which has been augmented by radial line or slotted templet positions. The prints used are rectified if shown to be necessary by this control. The controlled mosaic is assembled on a rigid mount of masonite, plywood, lightweight metal boards or similar material known as the mosaicking board. First, a projection at the final mosaic scale is constructed on this board and all available horizontal control which can be identified is plotted. The final mosaic scale can be at reproduction scale or 25 percent larger. The control information is then transferred to a transparent stable-base overlay upon which a radial line or slotted templet extension of this control is executed to locate the positions of nine points (peaks points, principal points, and transferred principal points) on each photograph.

6–11. Rectification by the Double Templet Method

a. Method. In order that all image points on the photographs will fit their plotted positions, it is necessary to rectify the photographs to correct for the effects of tilt or tilt and to enlarge or reduce the photograph to the scale of the projection on the mosaicking board. The autofocus rectifier (app B) provides a mechanical method for making this rectification and change of scale.
This method requires preparation of double templets of control. One templet (bottom templet) contains the control points at the same scale and in the same position as on the radial line plot. The other templet (top templet) contains the same control point in the position and scale of the photographs. Both templets are then inserted in the rectifier and the projection of the top templet in the head of the rectifier is made to coincide with the bottom templet on the easel. The bottom templet is replaced with positive photographic paper while the top templet is replaced with the negative film of the photograph. A rectified positive print is then made to the same scale as the bottom templet.

b. Preparing Bottom Templets.

(1) The radial line plot on a stable base film contains all the photo control points in their adjusted positions, including the principal points, transferred principal points, pass points, and geodetic control points. A templet of bristol board or of stable base film is placed under each principal point, and all the control within the area of that photograph is pricked through and marked on the templet. All symbols should be carefully centered with respect to the pricked points they identify. The symbols used are the same as those on the radial line plot.

(2) Sometimes a roll of stable base film is used as the bottom templet. When this is done, the groups of control points are arranged in the sequential order of the principal points to aid in finding templets quickly (fig. 6–12).

c. Preparing Top Templets.

(1) In preparing top templets each photo-

[Image 18x18 to 594x774]

Figure 6–12. Preparing top templets.

graph is taped to a drawing board and stable film base fastened down on top of the photograph. The same control points identified on the bottom templet are transferred from the photograph to the top templet and are similarly marked. Templets may be either individual sheet film templets covering one photograph each, or may be sequentially arranged on a roll of stable base film (fig. 6–13).

(2) Sometimes duplicate negatives can be used for the top templet. The control points can be pricked on the duplicate negative with a needle point positioning the film over the marked point on a light table. When time is critical, a red ink dot is used which can be removed later with a damp sponge. Use of duplicate film speeds up the work on a large mosaic job.

d. After the top and bottom templets have been prepared, they are ready for rectification.

6–12. The Autofocus Rectifier

a. Optical rectification is the process of projecting the image of a tilted aerial photograph into a horizontal reference plane to eliminate the image displacements caused by tilt of the aerial camera at the time of exposure. The photographic print produced by such a projection will possess all the geometrical characteristics of a vertical photograph taken at the same position in space. This projection is accomplished by means of a rectifier. To project the image correctly, certain mathematical relationships must be maintained between the rectifier’s negative plane, lens, and easel. Rectifiers for this purpose are of two main types: those in which the optical axis of the rectifier lens is the common reference or base direction of the instrument, and those in which the line between the principal point of the negative and the rectifier lens is the common reference. The autofocus rectifier is an example of the first type and the high-tilt rectifier is an example of the second type. Rectification with the autofocus rectifier is accomplished either by matching points to a control templet, or by the method of computed data; with the high-tilt rectifier, rectification is accomplished by the method of computed data.

b. The point-matching method is based upon the matching of the images of four or more points on an aerial negative or a transparent overlay of the negative to the correct horizontal positions of the same points plotted upon a templet or map. The matching is carried out by tilting the easel, changing the magnification, and rotating and displacing
the negative in its own plane until the projected images match the images on the easel templet or plot. Use of the control templet on the easel in conjunction with the aerial negative in the instrument is called the one-templet method of rectification, while use of the control templet on the easel in conjunction with a transparent overlay of the aerial negative in the instrument is called the two-templet method. Control points are sometimes difficult to identify in the projected image of the negative and since permanent marks should never be made on the original aerial negatives, the two-templet method is somewhat easier because all extraneous detail is eliminated on the transparent overlay.

c. The computed data method requires that the amount of tilt and its direction in the aerial photograph be known as well as the focal length of the aerial camera, the focal length of the rectifier lens, and the magnification ratio. The tilt data can be derived from an analysis of the contact print by any one of the standard procedures or from data incident to other instrumental use such as stereoplotting.

d. The autofocus rectifier and its operation are described in more detail in appendix B.