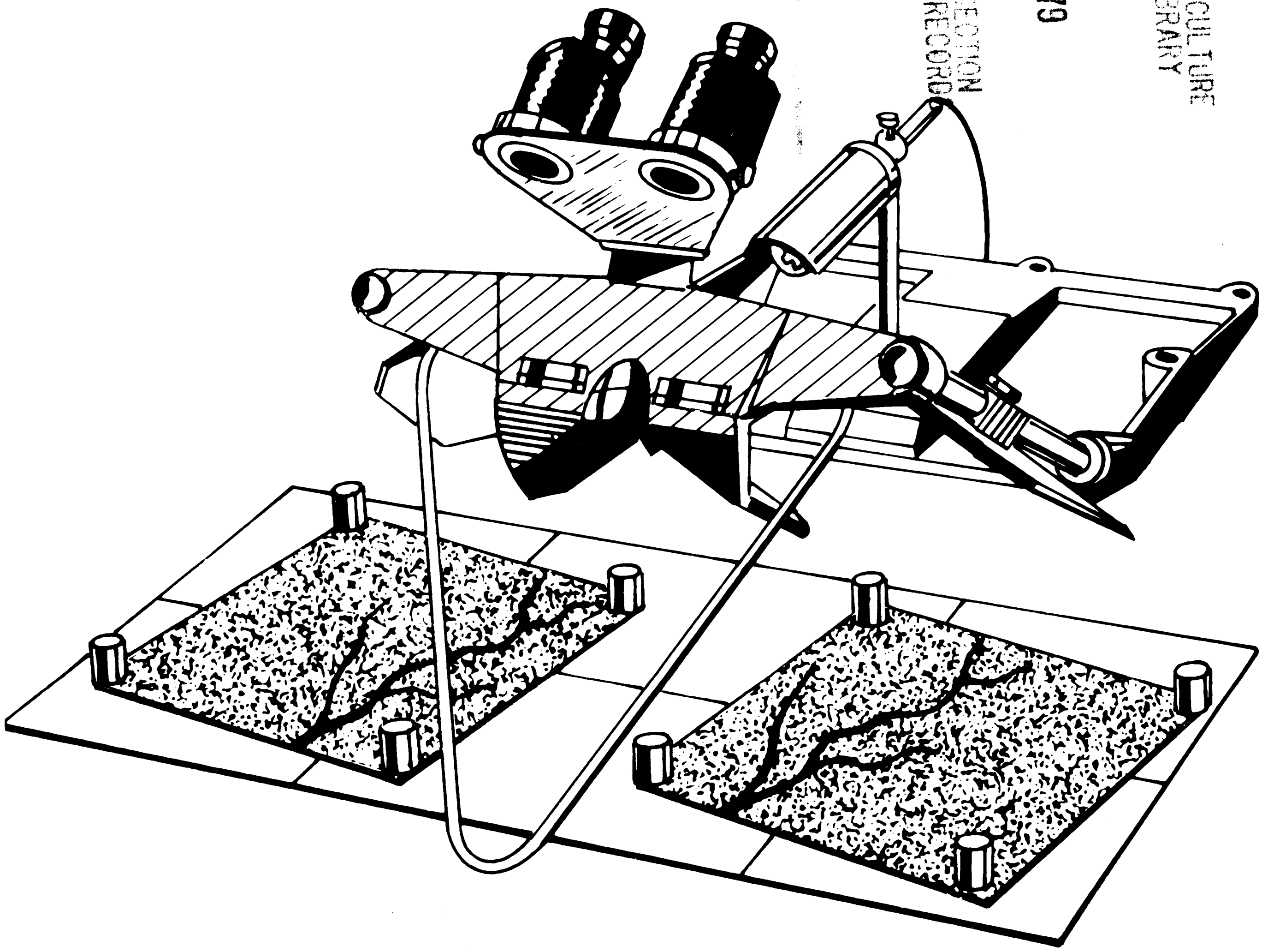
Forester's Guide to Aerial Photo Interpretation



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Forest Service

FORESTER'S GUIDE TO AERIAL PHOTO INTERPRETATION

Thomas Eugene Avery

U.S. Department of Agriculture

Forest Service

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This handbook is a revised and enlarged version of Occasional Paper 156, issued by the Southern Forest Experiment Station, New Orleans, La., in January 1957.

Dr. Thomas Eugene Avery, who prepared the original guide while employed by the Forest Service, is now an independent forest consultant and writer residing in Sedona, Ariz.

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FORESTER'S GUIDE TO AERIAL PHOTO INTERPRETATION

This handbook was written as a practical reference on techniques of aerial photo interpretation in forest inventory. It is for the forester with a casual knowledge of the subject. While oblique photographs are occasionally useful for interpretation, this manual emphasizes stereoscopic interpretation of vertical aerial photographs available from various agencies of the U.S. Department of Agriculture (USDA). Figure 1 (foldout, inside back cover) is an example of a vertical aerial photograph.

With training, the forester can use aerial photographs to locate property boundaries and trails, determine bearings and distances, identify classes of vegetation, and measure areas. Experience will enable him to improve the efficiency of forest inventories by distributing field samples on the basis of photo stratifications. In some instances, he may even be able to estimate timber volumes directly from the photographs.

While photo interpretation may make the forester's job easier, there are limitations. Accurate measurements of such items as tree diameter, form class, and stem defect are possible only on the ground. Aerial photographs are best used to complement, assist, or reduce field work rather than take its place.

TYPES OF AERIAL PHOTOGRAPHS

Oblique photographs are taken with the axis of the aerial camera at various angles between the horizon and the ground. *High* obliques show the horizon on the photograph; *low* obliques do not. An oblique photograph covers a larger area compared with a vertical photograph from the same altitude, but its usefulness is limited to fairly level terrain where the view is not obstructed by ridges. For this reason, and because obliques do not readily lend themselves to stereoscopic viewing, they are seldom used by foresters in the United States.

Vertical photographs are taken with the aerial camera pointed straight down at the ground, or as nearly so as feasible. Overlapping exposures in each flight line permit an interpreter to study vertical photographs three dimensionally with a stereoscope. Because such prints have become so useful for mapping and interpretation, the term "aerial photo" is normally assumed to denote a vertical photograph and will be thus applied in this handbook.

Mosaics are composite pictures assembled from as many individual, vertical photographs as may be required to cover a specified area; they are usually constructed to provide a pictorial representation and a planimetric approximation of a fairly extensive ground area. The principal kinds of mosaics, in order of ascending scale reliability are: (1) index or uncontrolled mosaics, (2) semi-controlled mosaics, (3) controlled mosaics, and (4) orthophotomosaics.

The *index mosaic* is simply an assembly of untrimmed contact prints that are pasted up in overlap and sidelap positions so that image detail is matched and the original flight-line position of each exposure is reconstructed. The entire layup is usually rephotographed at a smaller scale for use as a pictorial reference to individual prints. An *uncontrolled mosaic* is assembled in a similar fashion (i.e., without ground control) except that each frame is first trimmed down to its "effective" or non-overlapping area. Then, each trimmed portion is matched together like the segments of a jigsaw puzzle.

A *semi-controlled mosaic* differs from the uncontrolled type in that it is assembled with the aid of limited ground control points. It is thus intermediate in scale reliability, depending somewhat on the local relief of the area depicted.

A *controlled mosaic* is one that is directly tied to an extensive network of ground control points, and it is usually assembled from prints that are both rectified and ratioed. As a result, the mosaic will approximate planimetric map accuracy in regions of flat to gently rolling terrain. However, distortions due to relief are *not* eliminated in controlled mosaics, and *some* images will be displaced from their true plan positions.

OBTAINING AERIAL PHOTOGRAPHY

An *orthophotograph* is a reproduction, prepared from ordinary perspective photographs, in which image displacements caused by tilt and relief have been entirely removed. When these unique photographs are assembled into an *orthophotomosaic*, the result is a picture-map with both scale and planimetric detail of high reliability. When such mosaics are overprinted onto standard mapping quadrangles, they are referred to as orthophotoquads.

Users of this guide will ordinarily rely on prints of existent photography flown for public agencies. Thus there is no need here to discuss specifications for new aerial photography. Details of flight planning and photographic contracts are covered in the *Manual of Photogrammetry* and the *Manual of Photographic Interpretation* (*1*, *2*).[1]

Sources of cartographic information.—The National Cartographic Information Center (NCIC), established in 1974 by the U.S. Geological Survey, Department of Interior, provides a national information service to make cartographic data of the United States more easily accessible to the public and to various Federal, State, and local agencies. At present, more than 30 Federal agencies collect and prepare cartographic data. Existing data includes more than 1.5 million maps and charts, 25 million aerial and space photographs, and 1.5 million geodetic control points.

Much of this information is available by contacting NCIC at the following address:

National Cartographic Information Center
U.S. Geological Survey
507 National Center Rm. 1C101
Reston, VA 22092

NCIC does not obtain cartographic data from present holders; rather it collects and organizes descriptive information about the data, such as location, availability, and ordering instructions. Existing government and private data centers will continue to hold and distribute cartographic data, and some will provide local users with direct access to NCIC information through their existing public service facilities.

Sources of aerial photography.—A large proportion of the existing aerial photography of interest to foresters is held by Federal agencies within the Department of Agriculture. Principal among these are the Agricultural Stabilization and Conservation Service (ASCS), the Forest Service (FS) and the Soil Conservation Service (SCS).

The ASCS has the responsibility of contracting for aerial photography for all three agencies. It also has the responsibility for providing reproductions from all ASCS and FS photography and from SCS photography that is 2 or more years old. A central laboratory for ordering this photography is provided by ASCS:

Aerial Photography Field Office
ASCS/USDA
P. O. Box 30010
Salt Lake City, Utah 84125

Films, season, and date of photography.—Two types of black-and-white aerial film are in common use: panchromatic and infrared. Infrared is usually modified by a minus-blue filter to reduce contrast and improve image resolution. Panchromatic photography offers better resolution and lighter shadows but exhibits little tonal contrast among forest types. Modified infrared photography presents a maximum of contrast between conifers and deciduous hardwoods, but wet sites and shadows register in black, thus restricting interpretation.

In Western United States, where coniferous trees predominate, panchromatic film is more likely to be used. Conversely, foresters managing eastern hardwoods often prefer infrared photography because forest type separation is more definite. In figure 2, dark-toned pines (A) are readily differentiated from the light-colored upland hardwoods (B) on the infrared stereogram, but there is little tonal contrast on the panchromatic exposures. Also the farm pond at (C) is obvious on the infrared prints, but may be completely overlooked on the panchromatic photographs.

If measurements are needed for deciduous species, both kinds of photography should be taken during the growing season. Infrared is likely to be used specifically for forestry purposes and usually meets this requirement. On panchromatic photographs taken in winter, conifers can be distinguished from hardwoods, but interpretation of hardwood stand-sizes is difficult.

If there is a choice between photography of different dates, you should select the most recent. Also, if there is more than one source, you should choose which photograph shows the most information or use the photographs in conjunction. In regions characterized by rapid tree growth and frequent cuttings, the value of photos more than 5 years old is questionable.

With minor exceptions, ASCS and SCS photography is taken with black-and-white panchromatic film. A large percentage of the more recent FS photography is taken on color film, with most of the remainder taken on color infrared, black-and-white infrared, or panchromatic.

Photo scales and enlargements.—In earlier years, the negative scale of ASCS and SCS photography was commonly set at 1:20,000 (1,667

[1] Italic numbers in parentheses refer to Literature Cited, page 40.

feet per inch), while much of FS photography was set at a scale 1:15,840 (1,320 feet per inch). The FS has established a standard scale program of 1:24,000 for resource photography and 1:80,000 for high altitude photography.

Since about 1972, the negative scale of most ASCS photography has been set at 1:40,000 (3,333 feet per inch). Much of the FS photography acquired prior to the adoption of a standard scale was at a scale of 1:15,840 (1,320 feet per inch). Resource photography now used is at a scale of 1:24,000 (2,000 feet per inch). Scales of SCS photography are mostly in the range of 1:38,000 (3,167 feet per inch) or 1:58,000 (4,333 feet per inch).

The standard 9- by 9-inch contact prints can be enlarged, of course. Enlargements up to 38 by 38 inches are available, with commensurate increases in scale and image size. For example, a common product used by ASCS is an enlargement rectified to a scale of 1:7,920 (660 feet per inch) on sheets that measure 24 by 24 inches.

Unless sophisticated equipment is available, it is difficult to study enlargements stereoscopically. Therefore, contact prints are recommended for general use by foresters who must rely on simple pocket stereoscopes.

Paper surface, weight, and contrast.—Black-and-white prints ordered from ASCS are made on a medium-weight, semi-mat, resin-coated base material; as a result, the prints are both stable and water-resistant. Reproductions are also available in the form of positive film transparencies; as a rule, these provide greater sharpness and clarity of detail than ordinary prints.

When a specific degree of contrast is required, this should be indicated when ordering. If possible, the order should be accompanied by a sample print that illustrates the desired amount of density and contrast.

Coverage available.—USDA aerial photography covers more than 80 percent of the United States, including portions of Alaska and Hawaii. Coverage is updated periodically according to program needs; this results in new photography every 5 to 10 years for many areas.

The ASCS annually publishes "status maps" which are available free upon request. These maps show the most recent coverage available for a given area, the scale of photography, focal length of the camera lens, and number of photo index sheets required to cover a project area.

Ordering photography from ASCS.—Photo index sheets or index mosaics, showing the relative positions of all individual photographs within a given county (fig. 3a), can be examined at local offices of the Agricultural Stabilization and Conservation Service or the Soil Conservation Service. The number of index sheets per county varies from one to six or more. It is possible to visit an ASCS office, select desired photos from an index, and order them on the spot.

Forest Service indexes are usually available for inspection in local supervisor's offices or on ranger districts. Instead of conventional photographic indexes, the Forest Service now uses "spot indexes," i.e., maps showing the locations of photo centers (fig. 3b).

If you are interested in aerial photography of a distant county, you may wish to purchase an index of that county and make your selection. Again, your own county ASCS office will help you order the index and will provide assistance in selecting the photos that will best suit your needs. Prints are identified by a county symbol (or by a special state and county code), and by film roll and exposure number (fig. 1). Other items to specify are date of photography, scale, and type of reproduction (print size, weight, finish, contrast, etc.).

Special order blanks and current price lists may be obtained through local ASCS offices. Orders must be accompanied by advance payment, and 3 to 4 weeks should be allowed for delivery.

If you do not have access to the appropriate index sheet, an alternative is to outline the area of interest on a reliable map. This map can then be sent to the Aerial Photography Field Office in Salt Lake City with your inquiry.

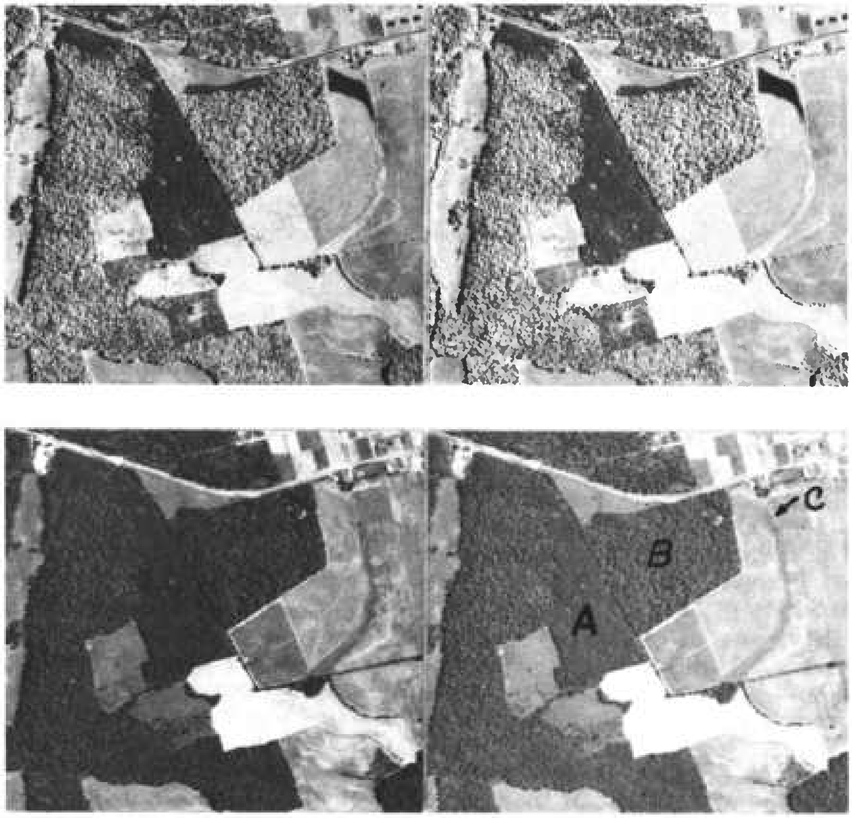

Figure 2.—Modified infrared (above) and panchromatic photography made in the North Carolina Piedmont during June. Exposures were made simultaneously with a dual aerial camera system. Scale is 1,320 feet per inch. Prints may be viewed three-dimensionally with a lens stereoscope.

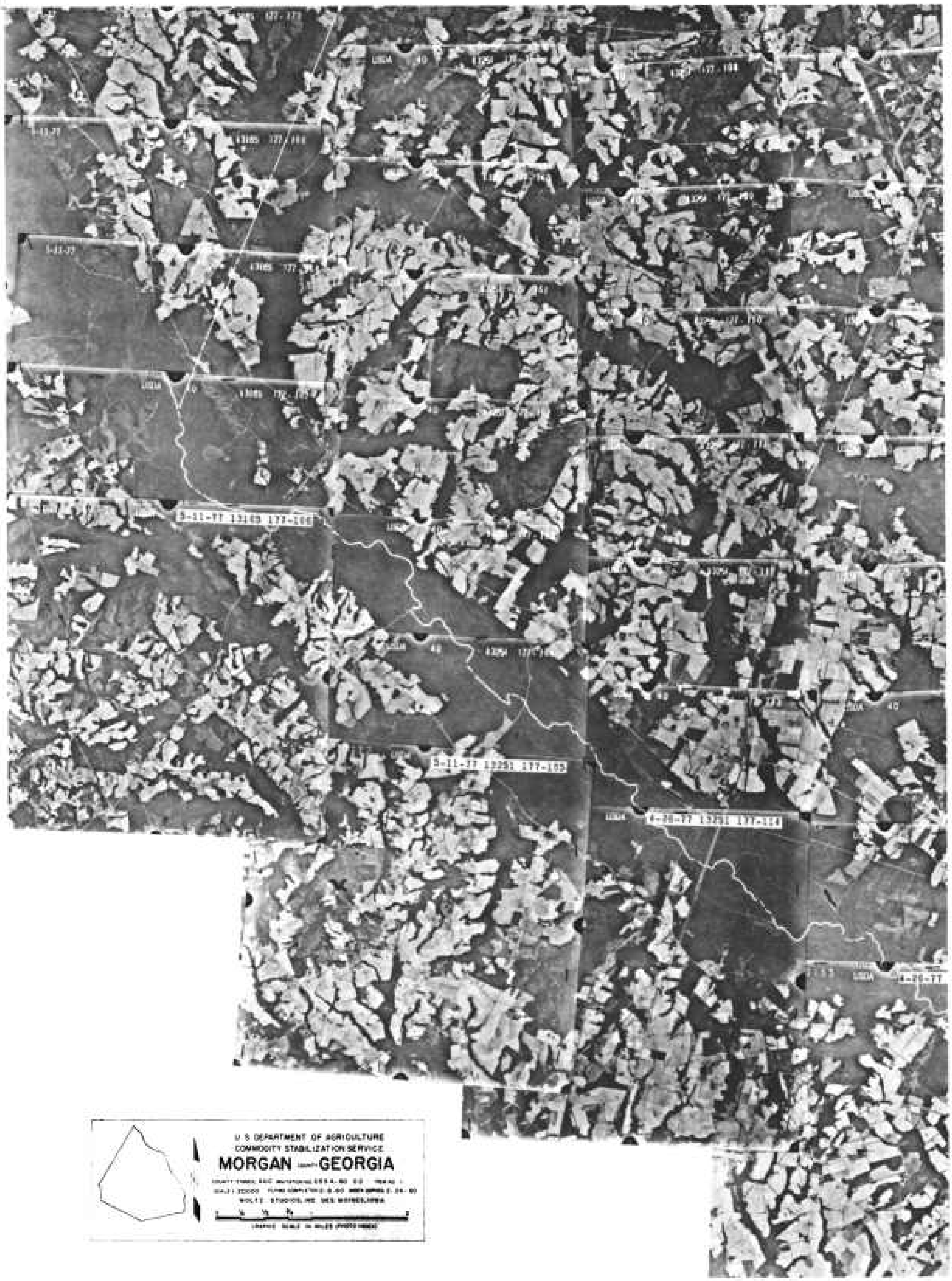

Figure 3a.—Two kinds of indexes to USDA aerial photography. The photo mosaic is the type used by the Agricultural Stabilization and Conservation Service and the Soil Conservation Service.

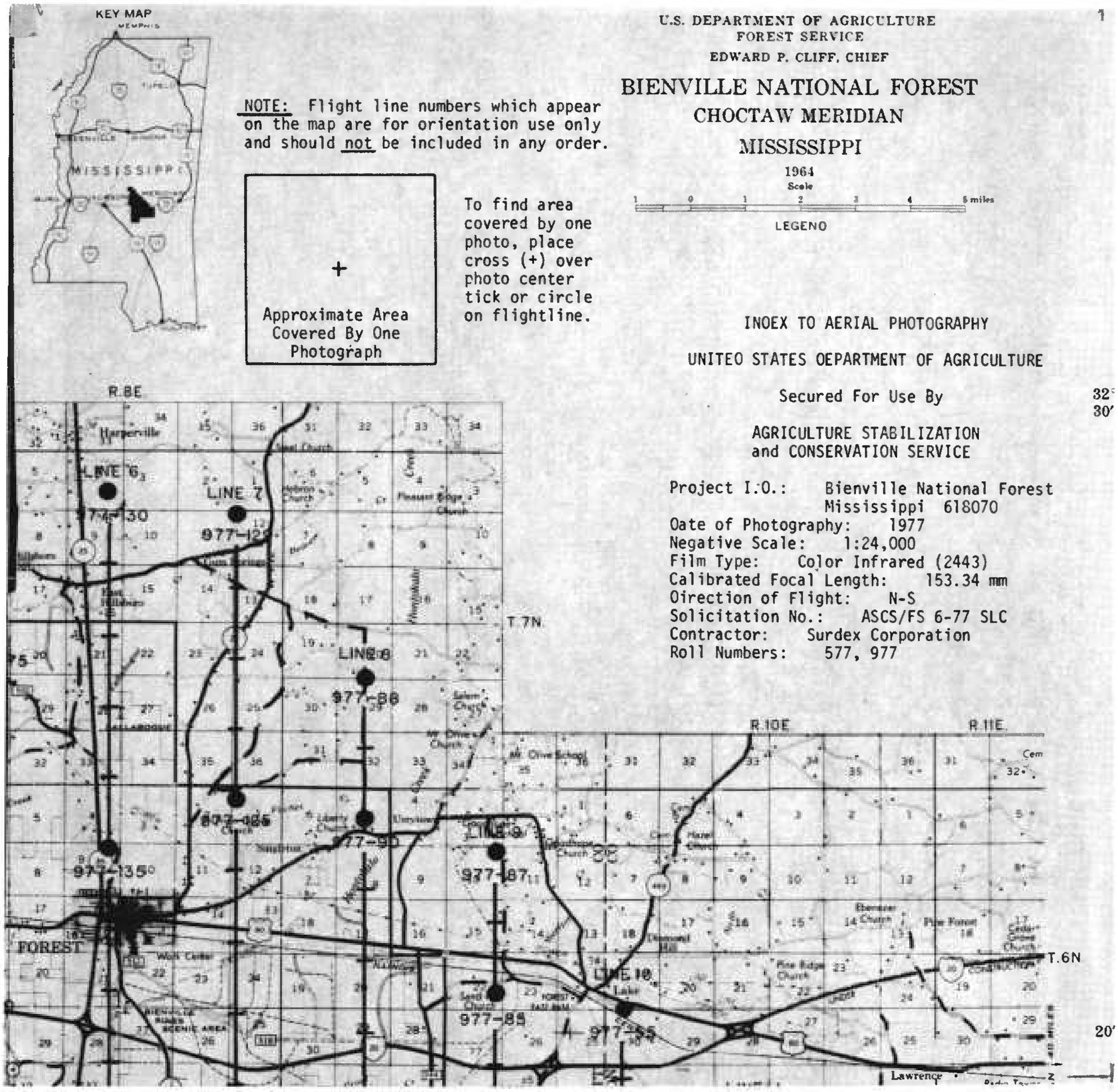

Figure 3b.—The "spot index" showing plotted positions of flight lines and photo centers, used by the Forest Service.

PREPARING PHOTOGRAPHS FOR STEREO-VIEWING

Equipment Needed

Equipment considered essential by one interpreter may be of limited use to another; nevertheless, the forester who anticipates a continued use of aerial photographs will probably find the following list closely approximates his minimum needs.

- Lens stereoscope, folding pocket type.
- Parallax bar or parallax wedge for measuring object heights.
- Engineer's scale, graduated to 0.02 inch.
- Tree crown-density scale.
- Tree crown-diameter scale.
- Dot grids for acreage determination.
- China-marking pencils for writing on photographs.
- Carbon tetrachloride and cotton for cleaning photographs.
- Drafting instruments, triangles, and drafting tape.
- Needles for point-pricking.
- Tracing table.
- Magnetic or spring-clipboard for holding stereo-pairs.
- Proportional dividers.

If purchased with discretion, the items can be obtained for less than $250. For a price list of photo interpretation aids available from the Forest Service, write to the Engineering Staff, Forest Service, U.S. Department of Agriculture, P.O. Box 2417, Washington, D.C. 20013.

Many foresters will already own drafting instruments, dot grids, and pocket stereoscopes. A satisfactory tracing table can be improvised by installing a uniform light source under a glass surface. Fluorescent tubes are better than incandescent bulbs because they produce less heat. A sheet of frosted cellulose acetate between two pieces of ordinary single-weight glass serves well when special frosted glass is not available.

If the forester uses aerial photographs regularly and becomes adept in interpretation and mapping, he may wish to acquire more expensive equipment, such as a mirror stereoscope, vertical sketchmaster, reflecting projector, or radial plotting devices. The *Manual of Photogrammetry* (*1*) contains information on such equipment.

Preparing the Photographs

Photographic flights are planned so that prints will overlap about 60 percent in the line of flight and about 30 percent between flight strips. For effective stereo-viewing, prints must be trimmed to the nominal 9- by 9-inch size, preserving the four fiducial marks at the midpoint of each of the edges (fig. 1). Then:

1. *Locate the principal point* (*PP*) *or center of each photograph.* Aline opposite sets of fiducial marks with a straightedge or triangle. Draw a cross at the center with a wedge-pointed pencil, and make a fine needle hole at the intersection.
2. *Locate the conjugate principal points* (*CPP's*) *on each photograph*—the points that correspond to PP's of adjacent photographs. Adjust the stereoscope until distance between centers of lenses corresponds with interpupillary distance (usually about 2.5 inches). Arrange the first two photographs of a given flight line so that corresponding gross features overlap. Shadows should be toward the observer; if they fall away from the viewer there is a tendency to see relief in reverse. Clip down one photograph. Move adjacent photograph in direction of line of flight until corresponding images on each print are about 2.2 inches apart. Place lens stereoscope over prints *parallel to line of flight* so that the left-hand lens is over the left photograph and the right-hand lens is over the same image on the right photograph. The area around the PP will be seen as a three-dimensional image. The movable photograph should then be fastened down. While viewing this area through the stereoscope, place a needle in the same area on the adjacent photograph until it appears to fall precisely in the hole pricked for the PP. This locates the CPP (fig. 1), though a monocular check should be made before the point is permanently marked. Repeat for all photographs; each will then have one PP and two CPP's except that prints falling at the ends of the flight lines will have only one CPP. Ink a 0.2-inch diameter circle around each PP and CPP (fig. 1).
3. *Locate the flight lines on each print by alining the PP's and CPP's.* Connect the edges of the alined circles with a fine ink line (fig. 1). Because of lateral shifting of the photographic plane in flight, a straight line will rarely pass through the PP and *both* CPP's on a given print.
4. *Determine the photo base length for each stereo-overlap* by averaging the distance between the PP and CPP on one print and the corresponding distance on the overlapping print. Measure to the nearest 0.02 inch and record on the back of each overlap. There will be two average base lengths for each print, i.e., one for each set of overlapping flight lines.

Alining prints for stereoscopic study.—A print is selected and clipped down with shadows toward the viewer. The adjacent print is placed with its CPP 2.2 inches from the corresponding PP on the first print. With flight lines superimposed, the second print is positioned and clipped down. The stereoscope is placed with its long axis parallel to the flight line and with the lenses over corresponding images. In this way an overlapping strip 2.2 inches wide and 9 inches long can be viewed by moving the stereoscope up and down the overlap area (fig. 4).

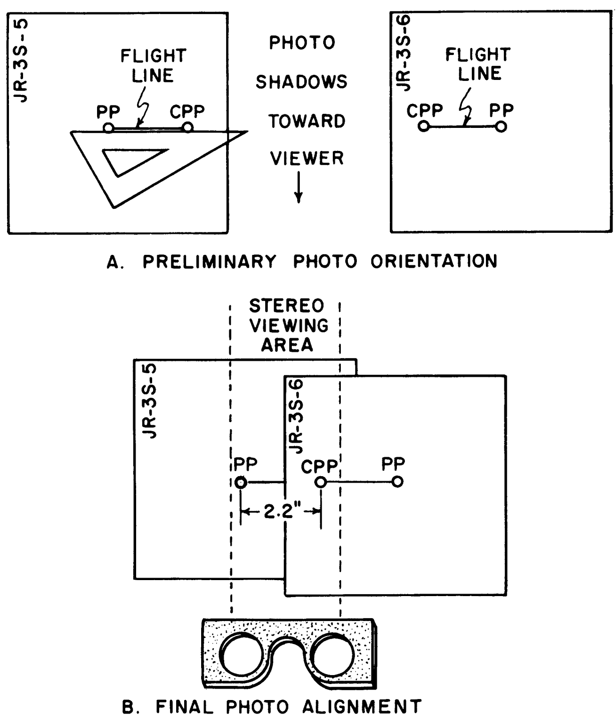

***Figure 4.*—Method of alining 9- by 9-inch contact prints for viewing with a lens stereoscope. Compare this diagram with figure 1.**

While the photos are still clipped down, the prints can be flipped into reverse position with the opposite photo on top. This presents another area of the overlap for stereo-viewing. To study the narrow strip between, the edge of one print must be curled upward or downward and the stereoscope moved parallel to the flight line until the "hidden area" comes into view (fig. 5).

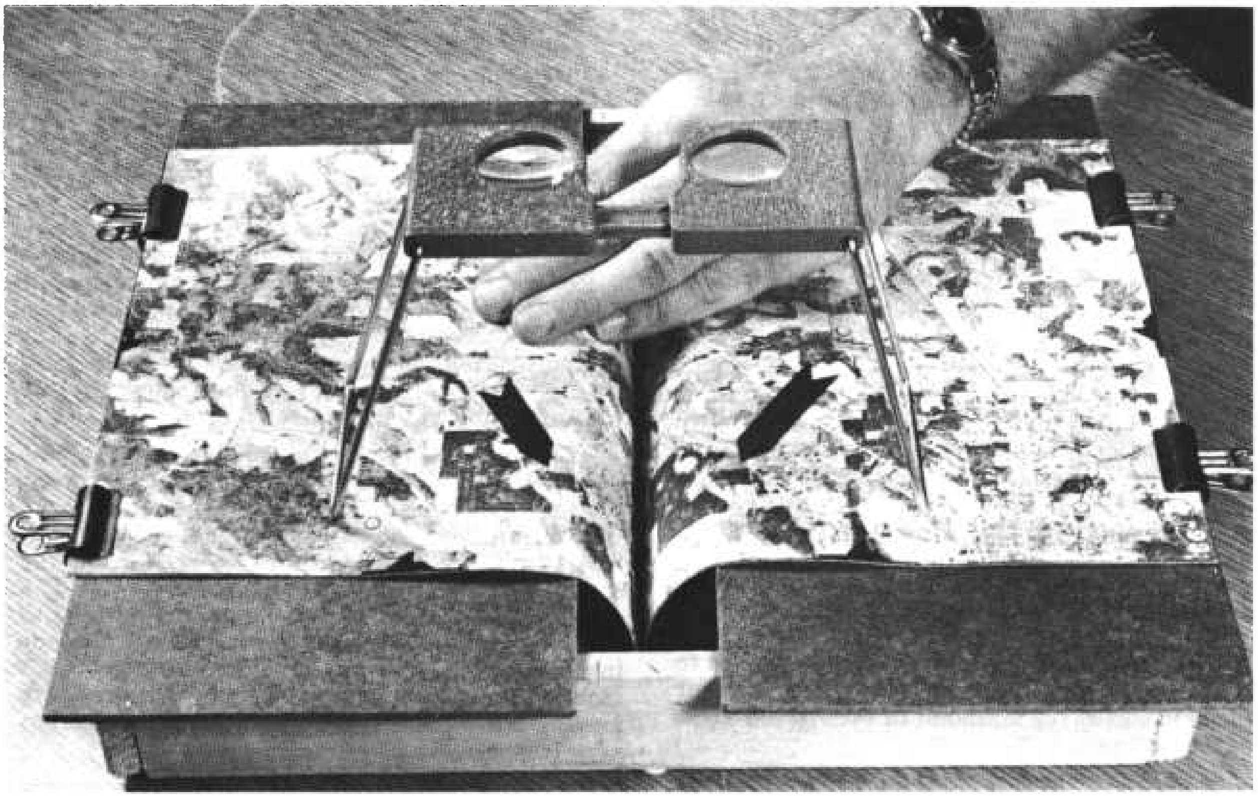

***Figure 5.*—Slotted clip board for viewing the "hidden area" of overlapping contact prints with a lens stereoscope. The area indicated by arrows cannot be stereoscopically studied when prints are lapped as in figures 1 and 4.**

PHOTO SCALE, BEARINGS, AND DISTANCES

The vertical aerial photograph presents a true record of angles, but measures of horizontal distances vary widely with changes in ground elevations and flight altitudes. The nominal scale (as 1:20,000) is representative only of the datum, an imaginary plane passing through a specified ground elevation above sea level. Calculation of the average photo scale will increase the accuracy of subsequent photo measurements.

Aerial cameras in common use have focal lengths of 6, 8.25, or 12 inches (0.5, 0.6875, or 1.0 ft.). This information, with the altitude of the aircraft above ground datum, makes it possible to determine the representative fraction (*RF*) or natural scale:

$$RF = \frac{\text{Focal length (ft.)}}{\text{Flying height above ground (ft.)}}$$

The height of the aircraft is rarely known to the interpreter, however, and photo scale is more often calculated by this proportion:

$$RF = \frac{\left[\text{Photographic distance between two points (ft.)}\right]}{\left[\text{Ground or map distance between same points (ft.)}\right]}$$

Determining scale from ground measurements.—Select two points on opposite sides of the print so that a line connecting them passes near the PP. If the points are approximately equidistant from the PP, the effect of photographic tilt will be minimized. (Tilt results when the camera axis deviates from the vertical at the instant of exposure. It is often present, but generally not enough to be readily noticed.) Points must be easily identifiable on the ground so that the distance between them can be precisely measured. Gas and power line rights-of-way, highways, and railroads offer clearings where ground distances can be quickly chained. It is not necessary to calculate the scale of every photograph in a flight strip. In hilly terrain, every third or fifth print may be used; in flat topography, every tenth or twentieth. Scales of intervening photographs can be obtained by interpolation.

Office checks of photo scale.—Scale determination from ground measurements is laborious and expensive; hence other methods should be used wherever possible. If a U.S. Geological Survey quadrangle sheet is available, the map distance can be measured and used in the formula, provided the same distance can be identified for photo measurement (fig. 6).

Another alternative is presented in areas of flat terrain where General Land Office subdivisions of sections, quarter-sections, and forties are visible on the photographs. Since the lengths of these subdivisions will be known, they can also be used as ground distances. A given section may rarely be exactly 5,280 feet on a side, but determining scale by this method is more accurate than accepting the nominal scale.

Compass bearings and distances.—Although flight lines usually run north-south or east-west, few photographs are oriented exactly with the cardinal directions. For this reason, a reference line must be located before bearings can be determined. The method described is used by field teams on the U.S. Forest Survey:

1. Select a straight-line feature such as a highway, section line, or field edge and determine its bearing. Draw this reference line on the photograph, extend it as necessary, and record the bearing (fig. 7).

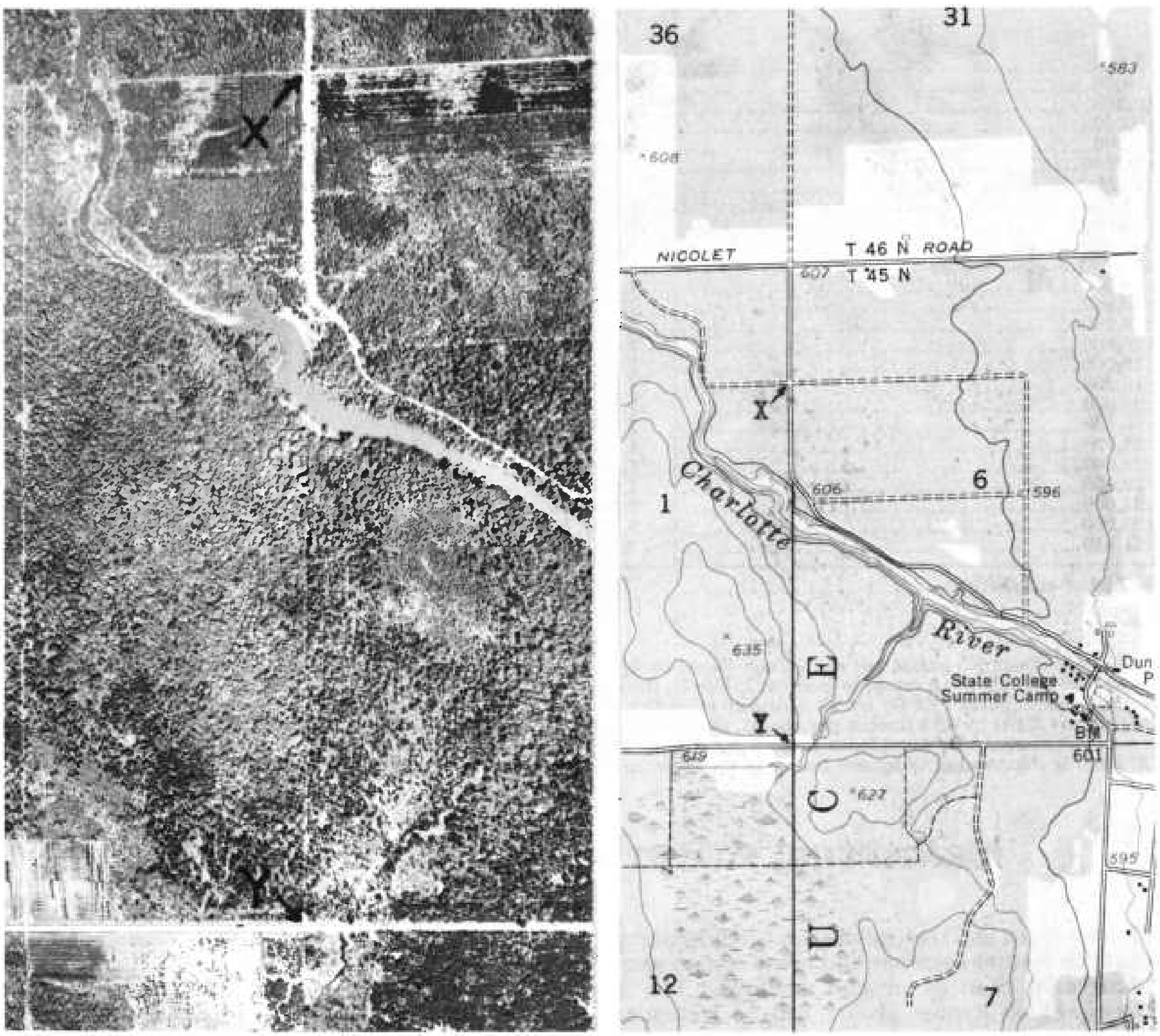

Figure 6.—Determination of photo scale from a U.S. Geological Survey map. Map scale is 1: 24,000 or 2,000 feet per inch. Map distance between X and Y is 2.00 inches, or 4,000 feet on the ground. Photo distance is 4.80 inches. Thus the photo scale is 4.80÷4,000×12, or 1: 10,000. (Courtesy of Abrams Aerial Survey Corporation.)

2. Pick a point of beginning (PB) from which the line of approach to a field location will be run. This should be some feature visible on both photograph and ground, such as a fence corner, barn, road intersection, or stream fork. Draw a line on the photograph from the PB to the location, and extend until it intersects the reference line. Measure the angle between the two lines with a protractor and determine the bearing of the line of approach.

3. Measure the distance between the PB and the field location to the nearest 0.01 inch and convert to feet or chains at the calculated photo scale. At a scale of 1:20,000, a measure of 0.01 inch equals 16.67 feet or about 25 links. In figure 7, the distance from PB to the center of the circular field plot is 1.15 inches, or about 29 chains. Common scale conversions are given in table 1.

TABLE 1.—*Scale conversions for vertical aerial photographs* [1]

Representative fraction (scale)	Feet per inch	Chains per inch	Inches per mile	Acres per square inch	Square miles per square inch
(1)	(2)	(3)	(4)	(5)	(6)
1:7,920	660.00	10.00	8.00	10.00	0.0156
1:8,000	666.67	10.10	7.92	10.20	.0159
1:8,400	700.00	10.61	7.54	11.25	.0176
1:9,000	750.00	11.36	7.04	12.91	.0202
1:9,600	800.00	12.12	6.60	14.69	.0230
1:10,000	833.33	12.63	6.34	15.94	.0249
1:10,800	900.00	13.64	5.87	18.60	.0291
1:12,000	1,000.00	15.15	5.28	22.96	.0359
1:13,200	1,100.00	16.67	4.80	27.78	.0434
1:14,400	1,200.00	18.18	4.40	33.06	.0517
1:15,000	1,250.00	18.94	4.22	35.87	.0560
1:15,600	1,300.00	19.70	4.06	38.80	.0606
1:15,840	1,320.00	20.00	4.00	40.00	.0625
1:16,000	1,333.33	20.20	3.96	40.81	.0638
1:16,800	1,400.00	21.21	3.77	45.00	.0703
1:18,000	1,500.00	22.73	3.52	51.65	.0807
1:19,200	1,600.00	24.24	3.30	58.77	.0918
1:20,000	1,666.67	25.25	3.17	63.77	.0996
1:20,400	1,700.00	25.76	3.11	66.34	.1037
1:21,120	1,760.00	26.67	3.00	71.11	.1111
1:21,600	1,800.00	27.27	2.93	74.38	.1162
1:22,800	1,900.00	28.79	2.78	82.87	.1295
1:24,000	2,000.00	30.30	2.64	91.83	.1435
1:25,000	2,083.33	31.57	2.53	99.64	.1557
1:31,680	2,640.00	40.00	2.00	160.00	.2500
Method of calculation	$\frac{\text{RFD}}{12}$	$\frac{\text{RFD}}{792}$	$\frac{63{,}360}{\text{RFD}}$	$\frac{(\text{RFD})^2}{6{,}272{,}640}$	$\frac{\text{Acres/sq. in.}}{640}$

[1] Conversions for scales not shown can be made from the relationships listed at the bottom of each column. With the scale of 1 :7,920 as an example (column 1, line 1), the number of feet per inch is computed by dividing the representative fraction denominator (RFD) by 12 (number of inches per foot). Thus, 7,920÷12=660 feet per inch (column 2). By dividing the RFD by 792 (inches per chain), the number of chains per inch is derived (column 3). Other calculations can be made similarly. Under column 4, the figure 63,360 represents the number of inches in one mile; in column 5, the figure 6,272,640 is the number of square inches in one acre; and in column 6, the number 640 is acres per square mile.

IDENTIFYING FOREST TYPES AND TREE SPECIES

Forest types and tree species can often be delineated with greater accuracy and lower cost on aerial photographs than by ground methods. The degree to which species groups can be recognized depends on the quality, scale, and season of photography; the type of film used; and the interpreter's training. A general knowledge of forest associations and plant ecology is helpful, but field experience in the specific area to be mapped is far more valuable.

A generalized map of forest regions in the United States is shown in figure 8. The tree species listed provide the first step in identification, i.e., the elimination of those cover types not likely to occur in a given locality. The second step, heavily dependent on a knowledge of local

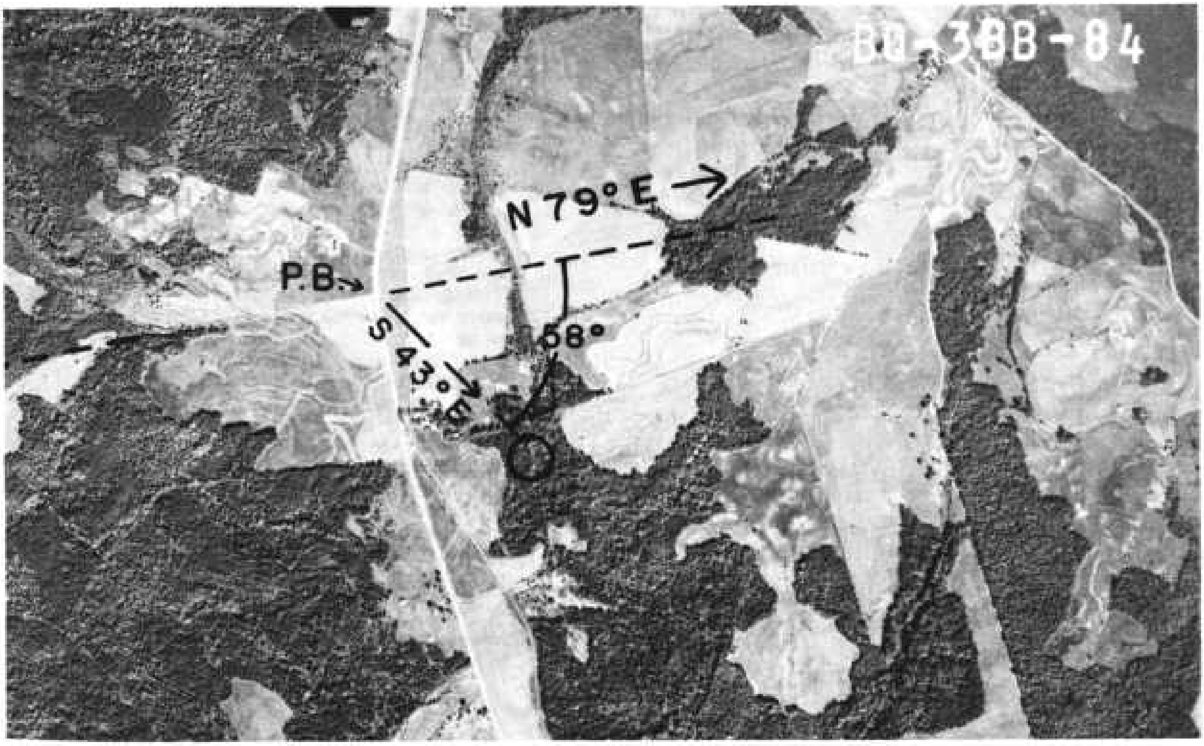

***Figure 7.*—Determination of compass bearing and distance to a field plot on a USDA contact print. Scale is 1,667 feet per inch.**

vegetation, is to establish which forest types may be encountered in the area to be mapped.

Recognition of an individual species, often feasible only on large-scale photography, is normally the culmination of intensive study. Obviously the forest interpreter must be familiar with branching patterns and crown shapes of all important species in his region. Mature conifers in sparsely stocked stands can often be recognized on 1:20,000 USDA photography by the configuration of their crown shadows falling on level ground (fig. 9). Studying oblique photographs of trees has been helpful to many foresters.

Recognition of species on vertical photographs also requires a familiarity with tree crowns as seen in overhead views (fig. 10). While overhead crown characteristics are not always apparent on 1:12,000 to 1:20,000 photographs, they can be highly useful on large-scale stereograms. Photo scales as large as 50 feet per inch have been utilized for tree species identifications in Canada (*16*, *20*).

Aside from shadows, crown shapes, and branching patterns, the features to consider in identifying tree species are photographic texture (smoothness or coarseness of images), tonal contrast, relative sizes of tree images at a given photo scale, and topographic location or site. Most of these are rather weak clues when observed singly, yet together they may be the final link in identification by elimination.

For some parts of the United States and Canada, vegetation keys are available aids in tree species recognition. Keys are useful for training new interpreters and for reference by more experienced personnel. Depending on the method of presenting diagnostic features, photo interpretation keys may be grouped into two general classes: *selective* keys and *elimination* keys. Selective keys are usually illustrations and descriptions of trees in a specific region, e.g., pines of Florida. They are organized for comparative use; the interpreter merely selects the key example that most nearly coincides with the forest stand he must identify. By contrast, elimination keys require the user to follow a step-by-step procedure, working from the general to the specific. One of the more common forms of elimination keys is the dichotomous type. Here the interpreter must continually select one of two contrasting alternatives until he progressively eliminates all but the item being sought.

A sample elimination key for identifying northern conifers is reproduced here. It may be used to identify tree species pictured in the large-scale stereograms in figure 11. In original form, this Canadian key had additional descriptive materials and illustrations such as those shown in figures 9 and 10 (*16*).

Vegetation keys are most easily constructed for northern and western forests where conifers predominate, because there are relatively few species to be considered and crown patterns are rather distinctive for each important group. By contrast, few if any, reliable keys are available for the highly variable hardwood forests of Southern and Eastern United States.

While the scope of this handbook does not permit a detailed treatment of all important forest types throughout the United States and Canada, examples are given in figures 12 through 18.

Key to the Northern Conifers [2]

1. Crowns small, or if large then definitely cone-shaped.	
2. Crown broadly conical, usually rounded tip, branches not prominent	cedar
2. Crowns have a pointed top, or coarse branching, or both.	
—crowns narrow, often cylindrical, trees frequently grow in swamps	swamp type black spruce
—crowns conical, deciduous, very light-toned in fall, usually associated with black spruce	tamarack
—crowns narrowly conical, very symmetrical, top pointed, branches less prominent than in white spruce	balsam fir
—crowns narrowly conical, top often appears obtuse on photograph (except northern white spruce), branches more prominent than in balsam fir	white spruce, black spruce (except swamp type)
—crowns irregular, with pointed top, has thinner foliage and smoother texture than spruce and balsam fir	jack pine
1. Crowns large and spreading, not narrowly conical, top often not well defined.	
3. Crowns very dense, irregular or broadly conical.	
4. Individual branches very prominent, crown usually irregular	white pine
4. Individual branches rarely very prominent, crown usually conical	eastern hemlock
3. Crowns open, oval (circular in plain view)	red pine

MAPPING FROM AERIAL PHOTOGRAPHS

Type maps are no longer considered essential by all foresters, but at times their cost may be justified. A general ownership map showing principal roads, streams, forest types, and condition classes may be desired for management planning and illustrative purposes. Also, in making a photo-controlled ground cruise where precise forest-area estimates are required, it may be necessary to measure stand areas on controlled maps of known scale rather than directly on contact prints. This is particularly important where topography causes wide variation in photo scales.

The wise interpreter will delineate only those types that he can consistently recognize. For maximum accuracy, type lines should be drawn under the stereoscope. As lines made with a china-marking pencil are easily removed with carbon tetrachloride or benzene, this method is recommended for preliminary work. Water-soluble ink is also suitable. Permanent markings can be made with drawing ink after types have been verified by ground reconnaissance.

Uncontrolled maps.—Where area measurement is not critical, simple uncontrolled type maps can be prepared at photo scale by direct tracing. Tract boundaries are drawn within the "effective area"[3] of alternate prints in each flight strip. Photographs are interpreted under the stereoscope, and all types and planimetric data are outlined. The detail is then traced onto frosted acetate or vellum, from one annotated print at a time. If boundaries are accurately drawn on interpreted prints to include all of the tract without duplication, the traced data from adjoining prints should match up without difficulty. To assure standardization in type recognition, it is desirable to have one man perform all interpretation work.

Uncontrolled maps are no more accurate for area measurement than the photographs from which they were prepared, but they may suffice for management plans and illustrations. Where flat terrain predominates, average photo scales vary only slightly and tracings may approach the accuracy of controlled maps.

Controlled maps.—Base maps of uniform scale may be required for photo-controlled ground cruises, as precise measures of forest area by type and stand size are essential for accurate volume estimates. In flat terrain, average photo scale can be determined and acreages measured directly on contact prints, but in steep topography variations in photo scale require the transfer of forest types to base maps for accurate area measurement. The most common way of adjusting variable photo scales to controlled maps is by constructing "radial line plots" or by preparing plat sheets from field notes of the General Land Office. As construction of a radial line plot is complex and has been ade-

[2] Reproduced by permission of L. Sayn-Wittgenstein, Forest Research Branch, Canada Department of Forestry (*16*).

[3] If 9- by 9-inch photographs with 60-percent endlap and 30-percent sidelap are assumed, alternate photographs will have effective areas of about 7.2 by 6.3 inches.

PRINCIPAL TREES OF THE FOREST REGIONS

NOTE.—The order indicates the relative importance or abundance of the trees

ROCKY MOUNTAIN FOREST

Northern Portion (Northern Idaho and Western Montana):

Lodgepole pine
Douglas-fir
Western larch
Engelmann spruce
Ponderosa pine
Western white pine
Western redcedar
Grand and alpine firs
Western and mountain hemlocks
Whitebark pine
Balsam poplar

Eastern Oregon, Central Idaho, and Eastern Washington:

Ponderosa pine
Douglas-fir
Lodgepole pine
Western larch
Engelmann spruce
Western redcedar
Western hemlock
White, grand, and alpine firs
Western white pine
Oaks and junipers (in Oregon)

Central Montana, Wyoming, and South Dakota:

Lodgepole pine
Douglas-fir
Ponderosa pine
Engelmann spruce
Alpine fir
Limber pine
Aspen and cottonwoods
Rocky Mountain juniper
White spruce

Central Portion (Colorado, Utah, and Nevada):

Lodgepole pine
Engelmann and blue spruces
Alpine and white firs
Douglas-fir
Ponderosa pine
Aspen and cottonwoods
Pinyons
Rocky Mountain and Utah junipers
Bristlecone and limber pines
Mountain-mahogany

Southern Portion (New Mexico and Arizona):

Ponderosa pine
Douglas-fir
White, alpine, and corkbark firs
Engelmann and blue spruces
Pinyons
One-seed, alligator, and Rocky Mountain junipers
Aspen and cottonwoods
Limber, Mexican white, and Arizona pines
Oaks, walnut, sycamore, alder, boxelder
Arizona cypress

PACIFIC COAST FOREST

Northern Portion (Western Washington and Western Oregon):

Douglas-fir
Western hemlock
Grand, noble, and Pacific silver firs
Western redcedar
Sitka and Engelmann spruces
Western white pine
Port Orford cedar and Alaska cedar
Western and alpine larches
Lodgepole pine
Mountain hemlock
Oaks, ashes, maples, birches, alders, cottonwoods, madrone

Southern Portion (California):

Ponderosa and Jeffrey pines
Sugar pine
Redwood and giant sequoia
White, red, grand, and Shasta red firs
California incense-cedar
Douglas-fir
Lodgepole pine
Knobcone and Digger pines
Bigcone-spruce
Monterey and Gowen cypresses
Sierra and California junipers
Singleleaf pinyon
Oaks, buckeye, California-laurel, alder, madrone

SOUTHERN FOREST

Pine Lands:

Shortleaf, loblolly, longleaf, slash, and sand pines
Southern red, black, post, laurel, cherrybark, and willow oaks
Sweetgum
Winged, American, and cedar elms
Black, red, sand, and pignut hickories
Eastern and southern redcedars
Basswoods

Alluvial Bottoms and Swamps:

Sweetgum and tupelos
Water, laurel, live, overcup, Texas, and swamp white oaks
Southern cypress
Pecan, water and swamp hickories
Beech
River birch
Ashes

Alluvial Bottoms and Swamps:

Red and silver maples
Cottonwoods and willows
Sycamore
Hackberry
Honeylocust
Holly
Redbay and sweetbay
Southern magnolia
Pond and spruce pines
Atlantic white-cedar

CENTRAL HARDWOOD FOREST

Northern Portion:

White, black, northern red, scarlet, bur, chestnut, and chinquapin oaks
Shagbark, mockernut, pignut, and bitternut hickories
White, blue, green, and red ashes
American, rock, and slippery elms
Red, sugar, and silver maples
Beech
Pitch, shortleaf, and Virginia pines
Yellow-poplar
Sycamore
Chestnut
Black walnut
Cottonwoods
Hackberry
Black cherry
Basswoods
Ohio buckeye
Eastern redcedar

Southern Portion:

White, post, southern red, blackjack, Shumard, chestnut, swamp chestnut, and pin oaks
Sweetgum and tupelos
Mockernut, pignut, southern shagbark, and shellbark hickories
Shortleaf and Virginia ("scrub") pines
White, blue, and red ashes
Yellow-poplar
Black locust
Elms
Sycamore
Black walnut
Silver and red maples
Beech
Dogwood
Persimmon
Cottonwoods and willows
Eastern redcedar
Osage-orange

Texas Portion:

Post, southern red, and blackjack oaks
Eastern redcedar, Ashe juniper

FLORIDA AND TEXAS FOREST—TROPICAL

Mangrove, false mangrove
Royal and thatch palms; palmettos
Florida yew
Wild figs
Seagrapes ("pigeon plum")
Blolly
Bahama lysiloma ("wild tamarind")
Wild-dilly
Gumbo-limbo
Poisontree
Inkwood
Button-mangrove
False-mastic ("wild olive")
Fishpoison-tree ("Jamaica dogwood")

NORTHERN FOREST

Northern Portion:

Red, black, and white spruces
Balsam fir
Eastern white, red ("Norway"), jack, and pitch pines
Hemlock
Sugar and red maples
Beech
Northern red, white, black, and scarlet oaks
Yellow, paper, sweet, and gray birches
Quaking and bigtooth aspens
Basswoods
Black cherry
American, rock, and slippery elms
White and black ashes
Shagbark and pignut hickories
Butternut
Northern white-cedar
Tamarack

Southern Portion (Appalachian Region):

White, northern red, chestnut, black, and scarlet oaks
Chestnut
Hemlock
Eastern white, shortleaf, pitch, and Virginia ("scrub") pines
Sweet, yellow, and river birches
Basswood
Sugar and red maples
Beech
Red spruce
Fraser fir
Yellow-poplar
Cucumber magnolia
Black walnut and butternut
Black cherry
Pignut, mockernut, and red hickories
Black locust
Tupelos ("blackgums")
Buckeye

ALASKA FOREST

Coast Forest:

Western hemlock (important)
Sitka spruce (important)
Western redcedar
Alaska cedar
Mountain hemlock
Lodgepole pine
Black cottonwood
Red and Sitka alders
Willows

Interior Forest:

White (important) and black spruces
Alaska paper (important) and Kenai birches
Black cottonwood
Balsam poplar
Aspen
Willows
Tamarack

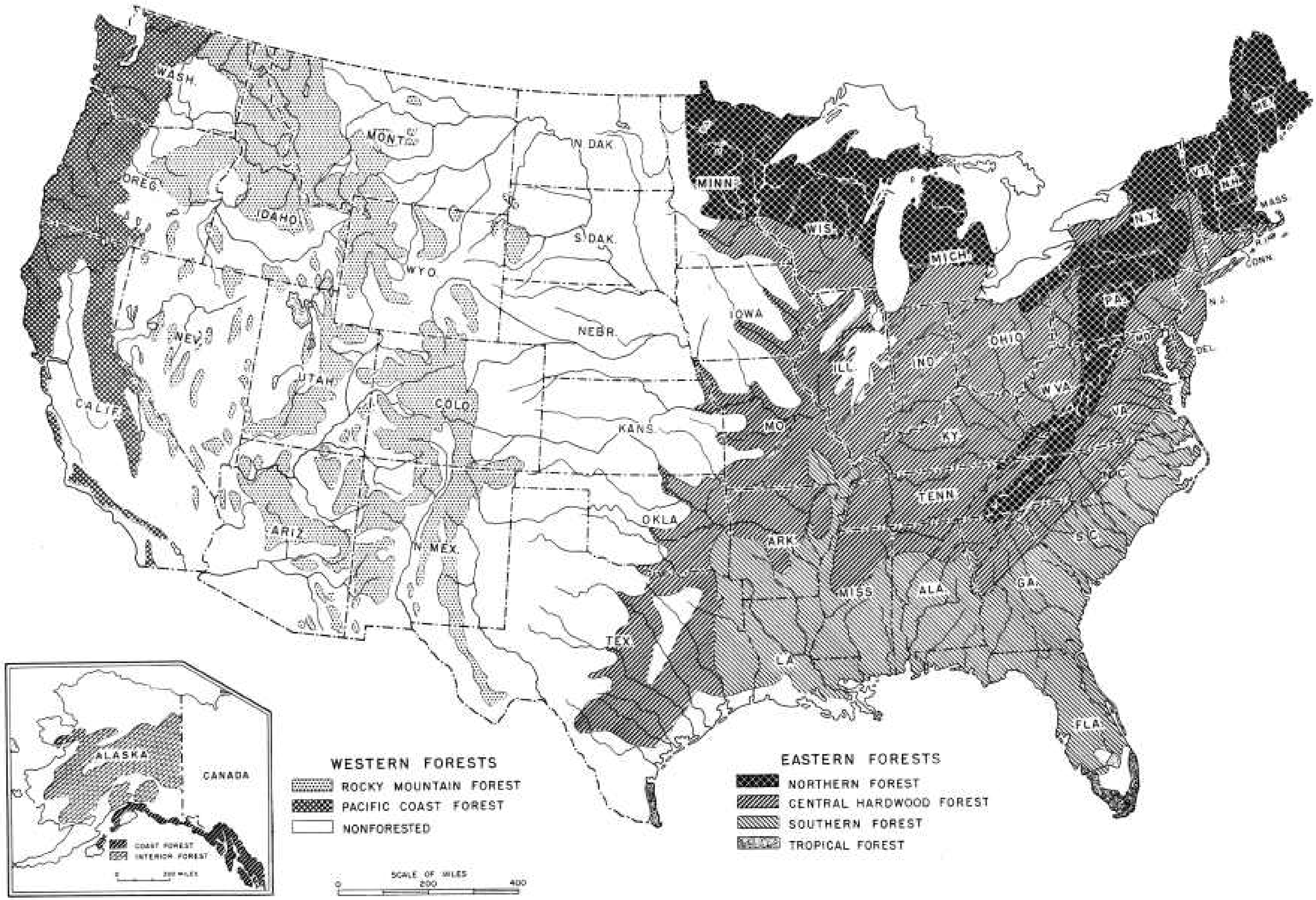

***Figure 8.*—Forest regions of the United States.**

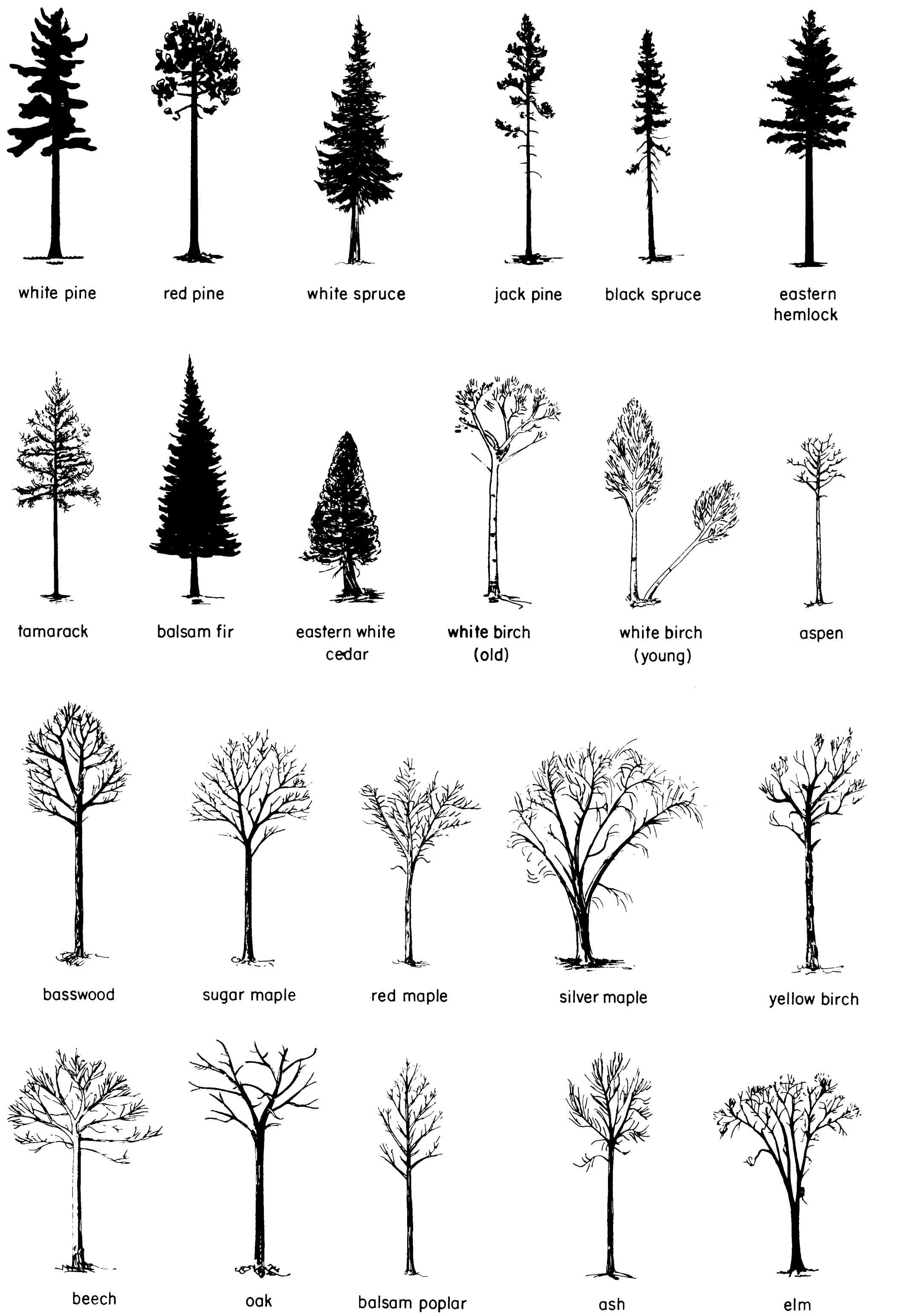

Figure 9.—**Silhouettes of forest trees. When tree shadows fall on level ground, they often permit identification of individual species. (Reprinted by permission of L. Sayn-Wittgenstein, Forest Research Branch, Canada Department of Forestry.)**

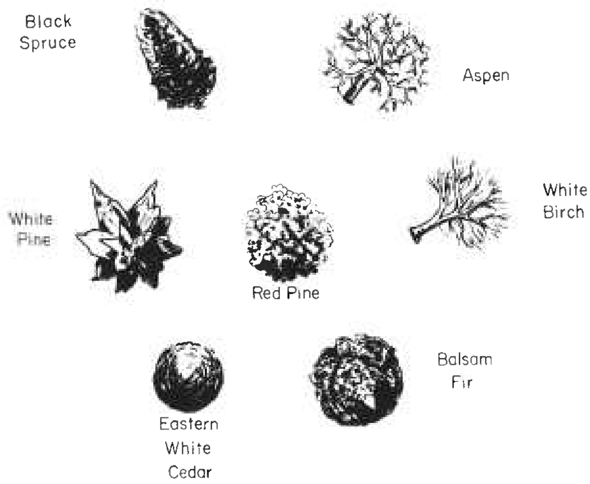

Figure 10.—Vertical views of tree crowns. Compare with stereograms in figure 11. (Reprinted by permission of L. Sayn-Wittgenstein, Forest Research Branch, Canada Department of Forestry.)

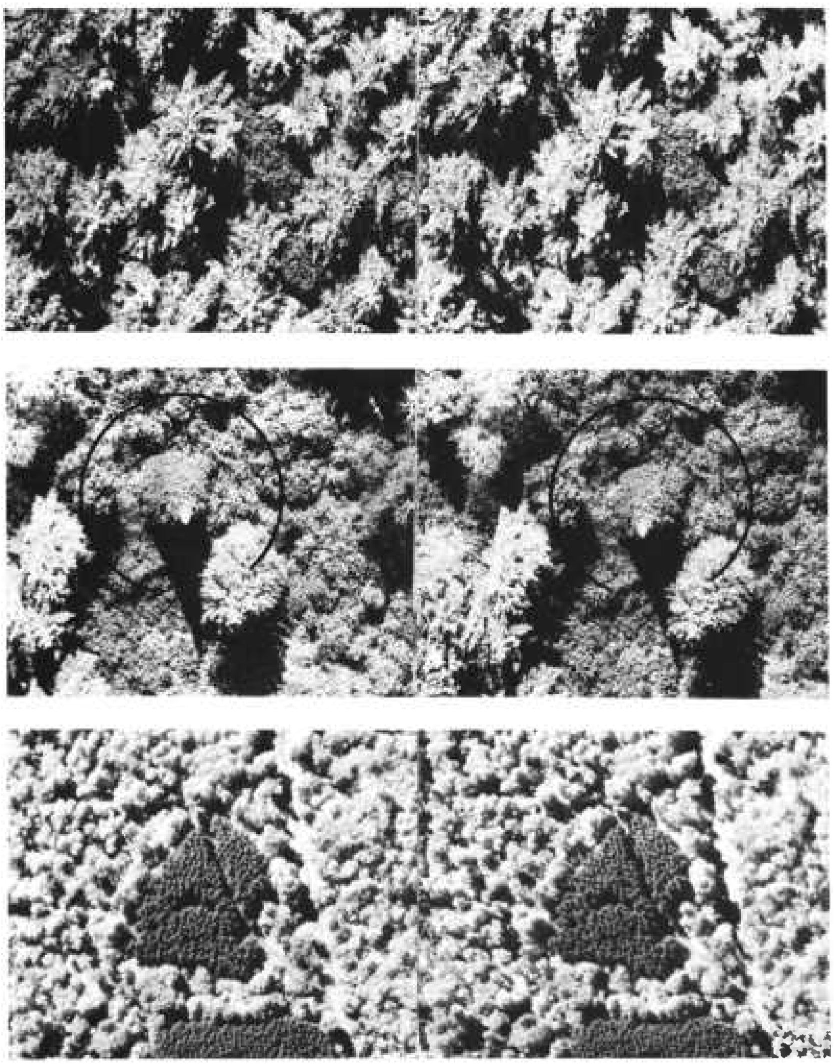

Figure 11.—Large-scale stereograms showing star-shaped white pine crowns (top), cone-shaped balsam fir crowns (center), and a red pine plantation surrounded by a stand of basswood (bottom). The two upper stereograms are on panchromatic film at a scale of 50 feet per inch. The bottom pair is on infrared film at a scale of 330 feet per inch. (Reprinted by permission of L. Sayn-Wittgenstein, Forest Research Branch, Canada Department of Forestry.)

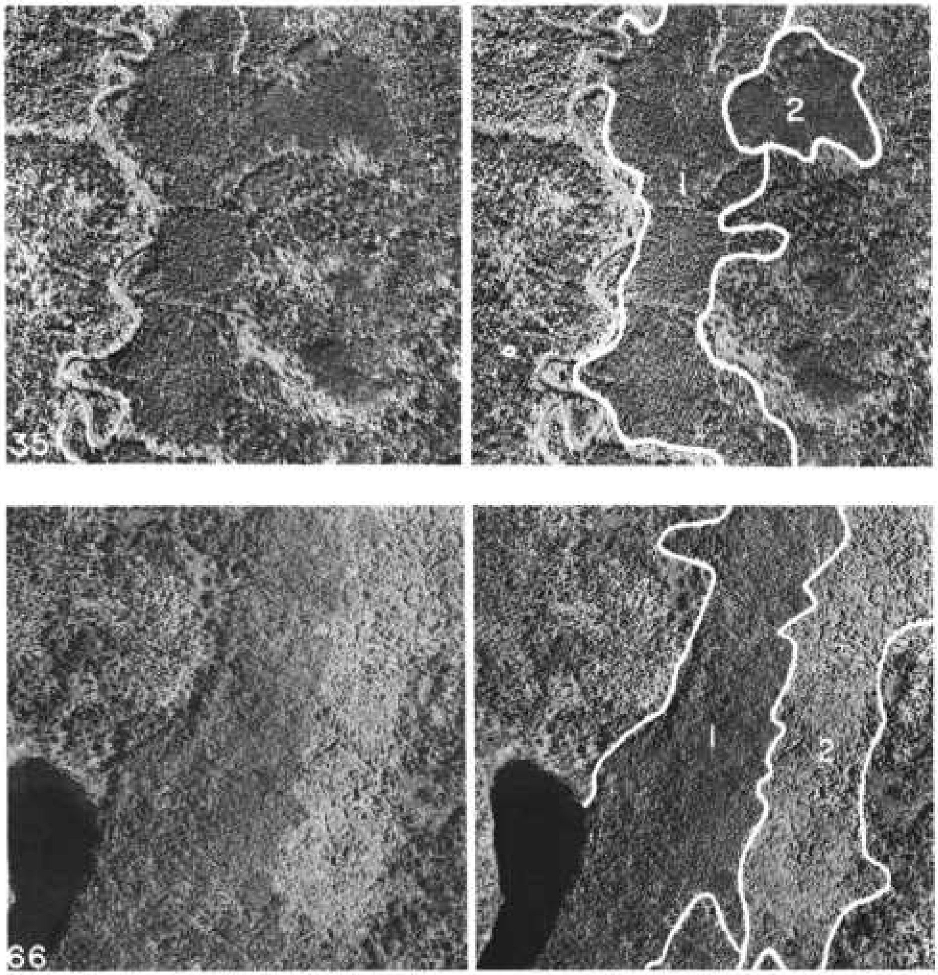

Figure 12.—Summer panchromatic photography in Ontario. In the upper stereogram (No. 35) stand 1 is balsam fir and stand 2 is black spruce. In the lower stereogram (No. 66) stand 1 is aspen-white birch and stand 2 is beech. Scale is 1,320 feet per inch. (Reprinted by permission of V. Zsilinszky, Ontario Department of Lands and Forests, Canada.)

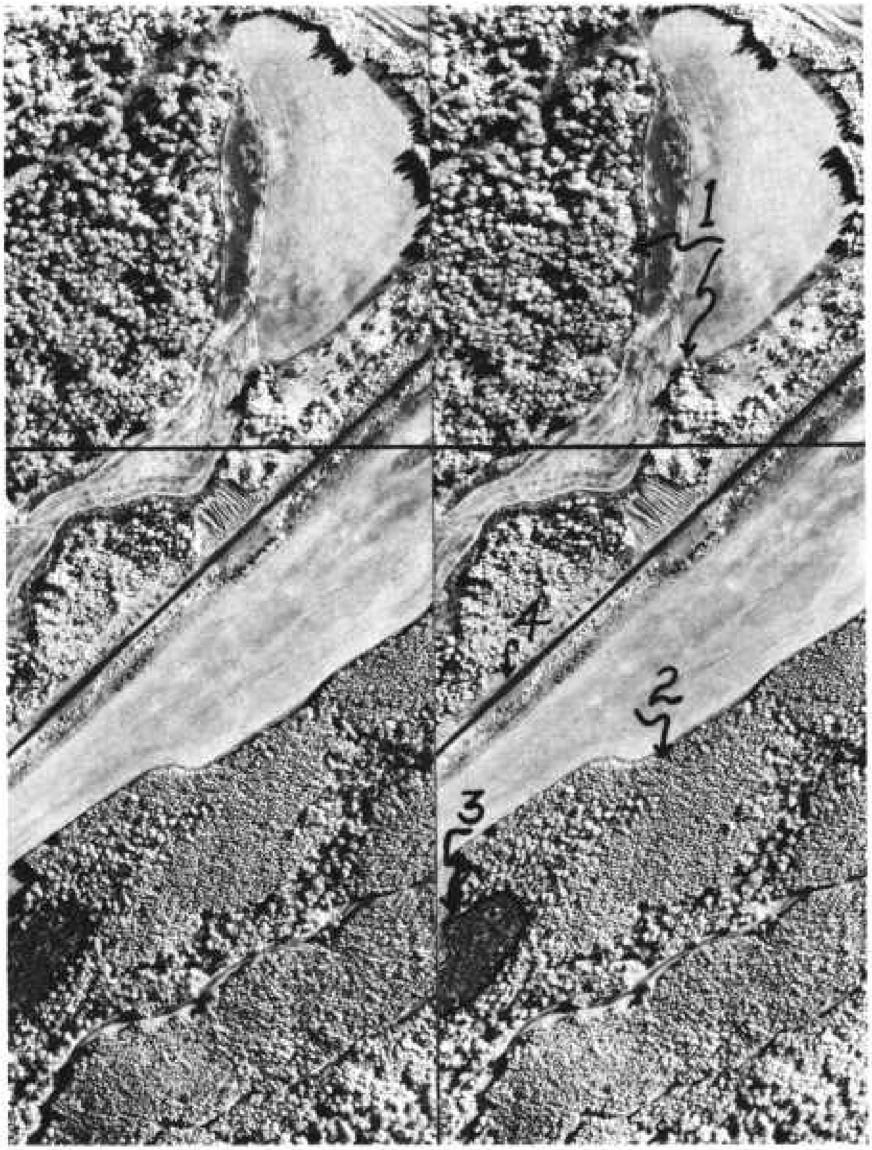

Figure 13.—Infrared stereogram illustrating forest associations in central Alaska. Types are (1) paper birch, (2) aspen, and (3) white spruce. A portion of the Alaska Railroad is shown at (4). Scale is about 420 feet per inch.

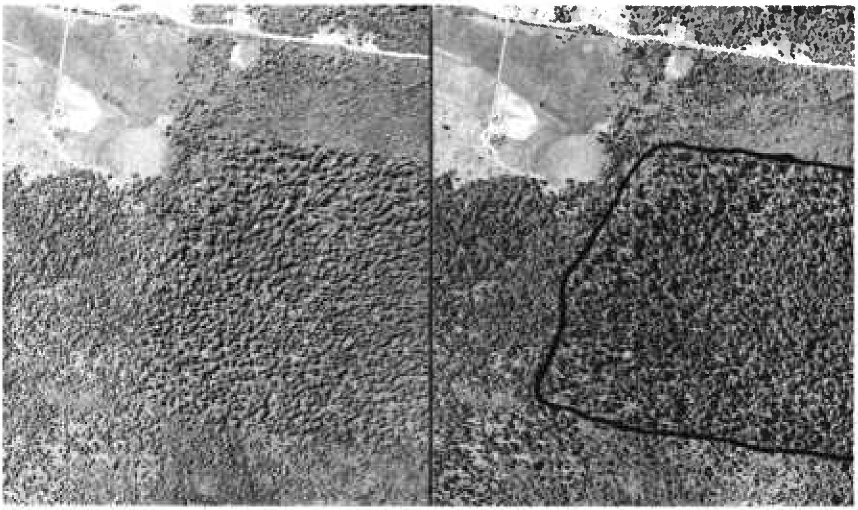

Figure 14.—USDA panchromatic stereogram from Del Norte County, Calif. Enclosed trees are primarily redwood, with lesser numbers of Douglas-fir, spruce, and hemlock. Clear stereo-viewing is hindered by the heavy displacement of trees, some of which are 250 to 300 feet tall. Scale is about 1,667 feet per inch.

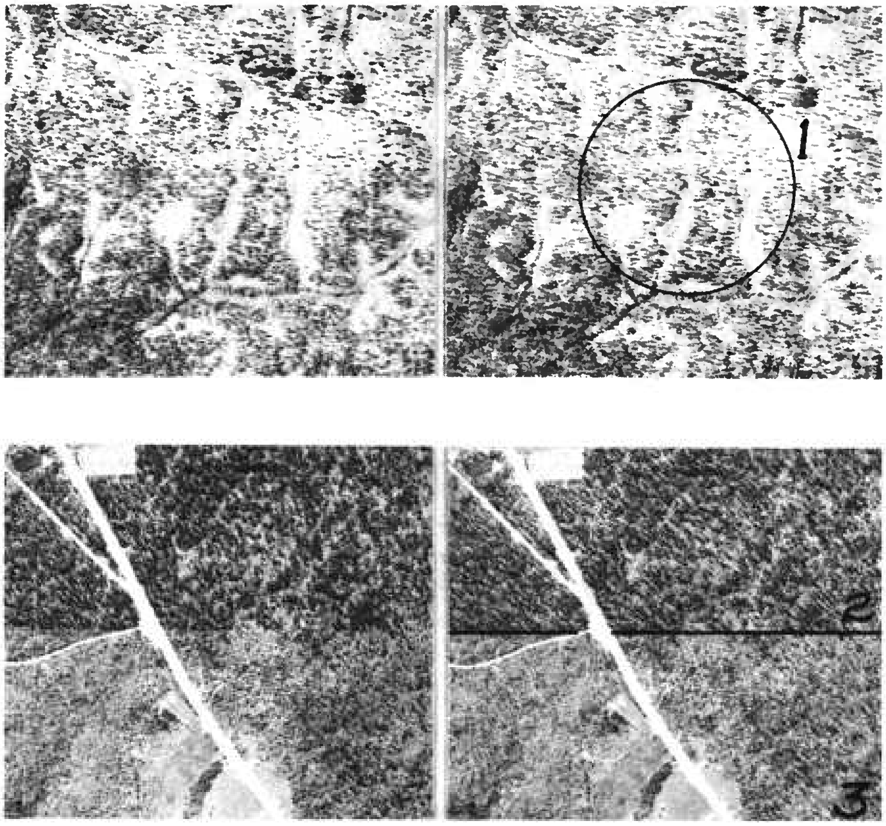

Figure 15.—USDA panchromatic stereograms from Jackson (above) and Clarke Counties, Miss. At (1) is a natural stand of longleaf and slash pines; loblolly-shortleaf pines are pictured at (2) and leafless upland hardwoods at (3). Scale is about 1,667 feet per inch.

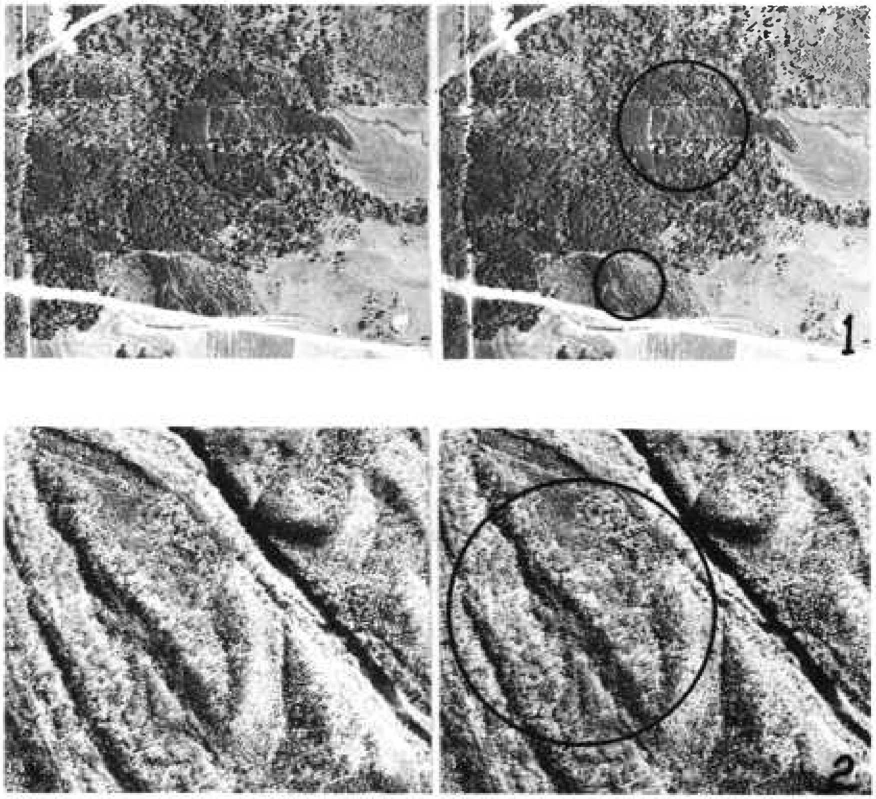

***Figure 16.*—USDA panchromatic stereograms from Columbia (above) and Sevier Counties, Ark. Two loblolly pine plantations are pictured at (1), while the mountainous terrain at (2) supports a mixture of upland hardwoods and shortleaf pine. Scale is about 1,667 feet per inch.**

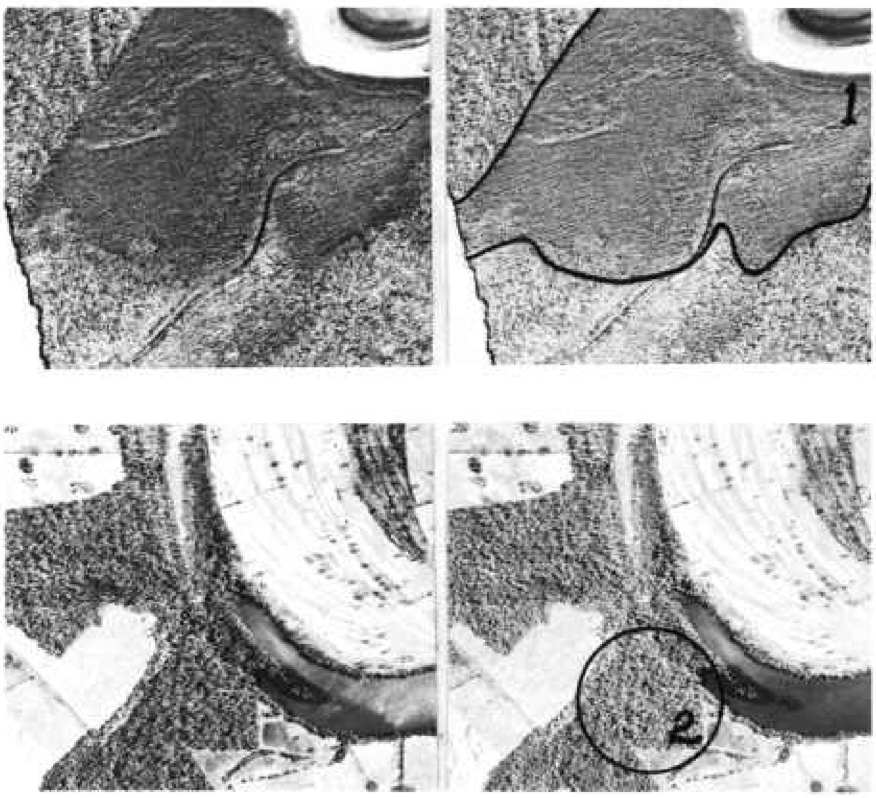

***Figure 17.*—USDA panchromatic stereograms from Bolivar County, Miss. The fine-textured stand at (1) is willow and cottonwood growing on a recent deposition of sand and silt. At (2) is a stand of bottom-land hardwoods, i.e., oaks, gums, maples, and other wet-site species. Scale is about 1,667 feet per inch.**

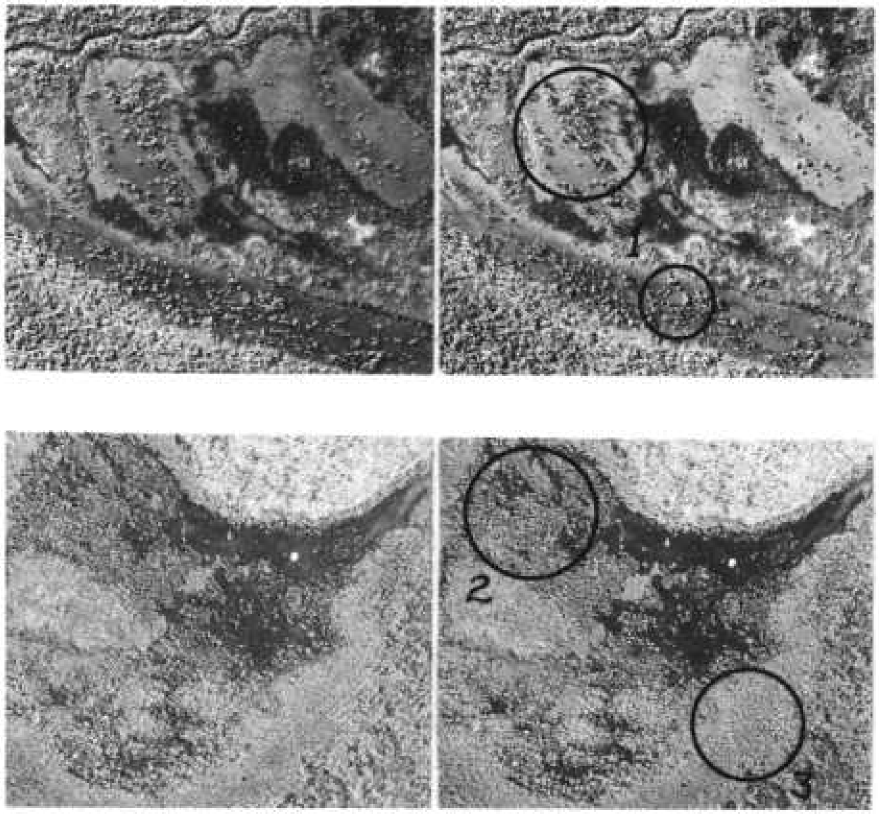

***Figure 18.*—USDA panchromatic stereograms from Lafayette County, Ark. Pure stands of southern cypress are shown at (1); the irregular and somewhat star-shaped crowns of this species can be clearly discerned against the water. At (2) is a mixture of cypress and tupelo gum, while a pure stand of tupelo gum is pictured at (3). Scale is about 1,667 feet per inch.**

quately treated in several readily available publications (*1, 17, 18*), it will not be reviewed here.

General Land Office (GLO) plats.—Most of the United States west of the Mississippi River and north of the Ohio River, plus Alabama, Mississippi, and portions of Florida, was originally subdivided under the U.S. Public Land Survey. Township, range, and section lines are often visible on aerial photographs. If enough such lines and corners can be identified, GLO plats can be constructed for use as base maps from field notes available at State capitals or county offices. To do this, a GLO plat showing sections, quarter sections, and forties is drawn to average photo scale from field notes. As many as possible of the same lines and corners are pinpointed on the aerial photographs, preferably arranged in a systematic framework throughout the forest property. Ownership maps, county highway maps, and topographic quadrangle sheets may help to identify such corners, but additional points must usually be found by taking the photographs into the field. The accuracy of this method depends upon the number of grid lines and corners which can be pinpointed on the aerial photographs. The technique described is adapted from Johnson (*7*).

When photo interpretation of forest types has been completed, the detail is transferred to the plat, one square of the grid being completed at a time. If the plat and photographs are of the same scale, transfer can be made by direct tracing on a light table; where scales differ, a vertical sketchmaster is recommended (fig. 19). By moving this instrument up or down on its adjustable legs, maps can be drawn at scales of seven-tenths to one and one-half times the scale of the contact print. The sketchmaster accommodates a single, annotated print, which is placed face up on the platform under a large mirror. Photo images are reflected from the large mirror to a semisilvered mirror in the eyepiece housing. The semitransparent eyepiece mirror thus provides a monocular view of the reflected photo image superimposed on the base map. When the grid points on photograph and map have been matched, the transfer of detail becomes a simple procedure (fig. 20).

Topographic and county maps.—Topographic quadrangle sheets and county highway maps are often useful in preparing base maps and identifying features on aerial photographs. When available, 7½-minute quadrangle maps at a scale of 1:24,000 provide excellent base maps, and can be

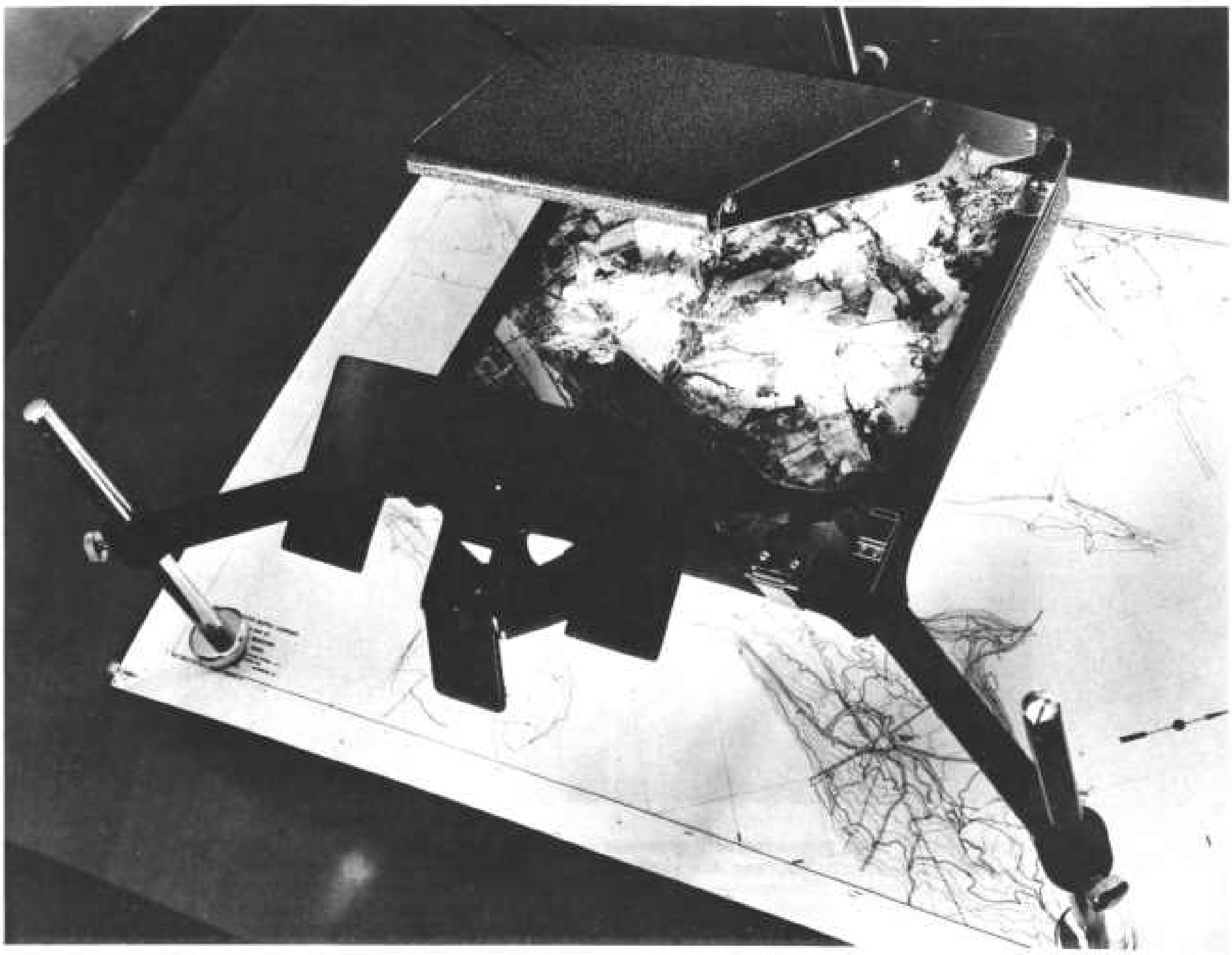

***Figure 19.*—Vertical sketchmaster for transferring detail from single contact prints to a base map. A semisilvered eyepiece mirror enables the operator to view photograph and map simultaneously. (Courtesy of Aero Service Corporation.)**

purchased for about 30 cents per copy. Maps for areas west of the Mississippi River, including all of Louisiana and Minnesota, can be purchased from

U.S. Geological Survey
Distribution Section
Federal Center
Denver, Colo. 80225

For areas east of the Mississippi River, including Puerto Rico and the Virgin Islands, maps may be purchased from

U.S. Geological Survey
Distribution Section
Washington, D.C. 20240

Maps of Hawaii may be ordered at either address. All orders must be paid in advance. Other sources of topographic quadrangle maps are the Maps and Surveys Branch of the Tennessee Valley Authority, Chattanooga, Tenn.; the Mississippi River Commission, U.S. Army Corps of Engineers, Vicksburg, Miss.; and the U.S. Coast and Geodetic Survey, Department of Commerce, Washington, D.C.

County maps, usually obtained from State highway departments, may serve as base maps when a high level of accuracy is not required. They show township, range, and section lines, in addition to geographic coordinates (longitude and latitude) to the nearest 5 minutes. They are usually printed at a scale of about one-half inch per mile. Although bearings of section lines are not shown, such maps are more reliable than oversimplified plats showing idealized sections oriented exactly with the cardinal directions. Portions of county maps can be enlarged to photo scale and sections subdivided into quarters or forties by proportionate measurement. These maps may be especially helpful in preparing GLO plats as previously outlined.

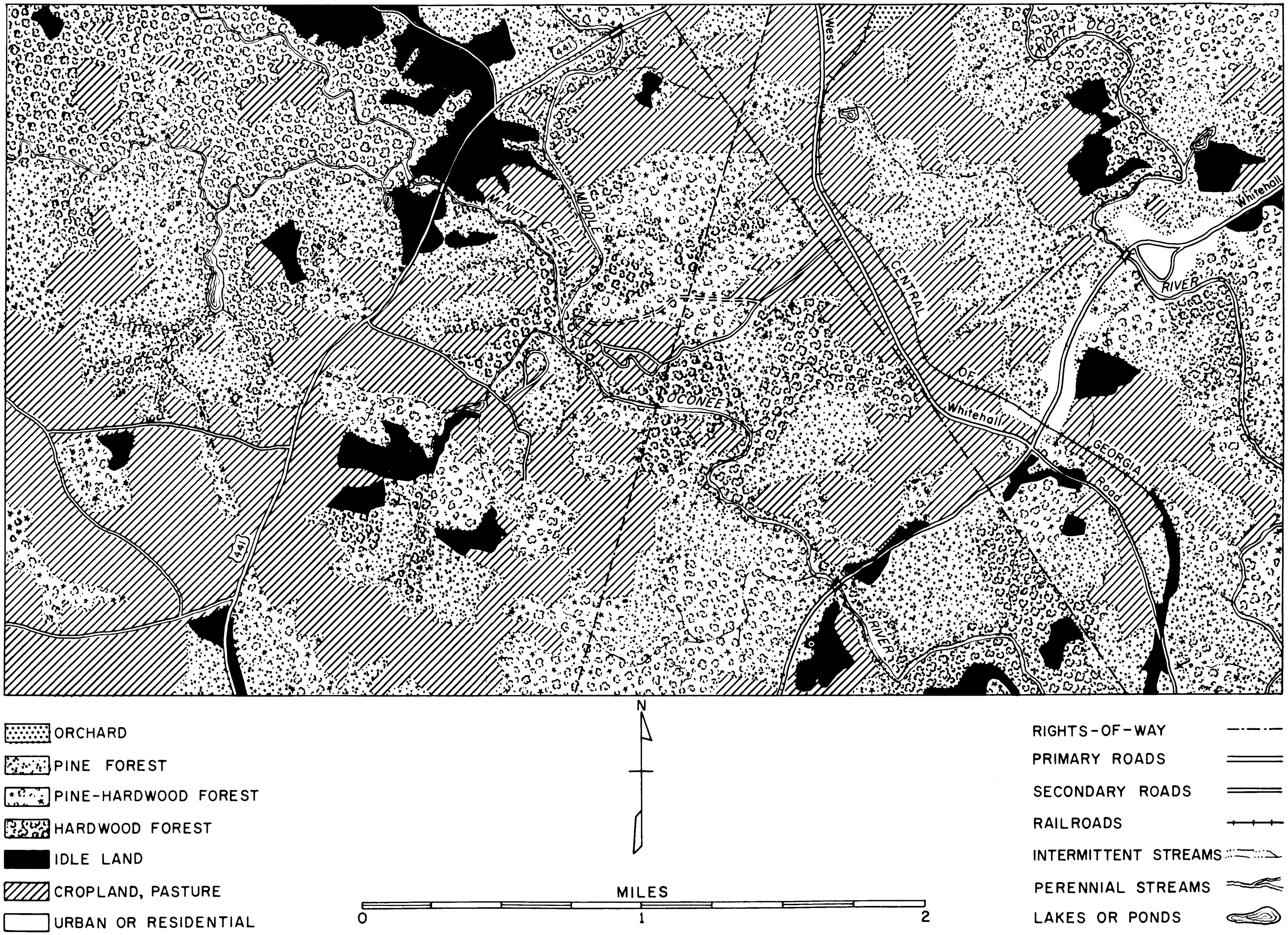

Figure 20.—**Photo mosaic assembled from 1960 USDA prints, and corresponding map compiled with the vertical sketchmaster. The area is in Clarke County, Ga.**

MEASURING AREAS

Both aerial and ground cruising require accurate measurement of forest areas. Photographs offer an inexpensive means of making such determinations. In locations where photo scales are not appreciably altered by topographic changes, areas can be measured directly on contact prints. Greater accuracy is possible if forest types are transferred to controlled base maps before area is determined. This procedure is essential for mountainous terrain. On the other hand, if only relative proportions of the forest types are needed and measurements are limited to the effective areas of contact prints, no bias results from using photographs, even when local relief ranges from 500 to 1,000 feet (*12*, *19*). (This statement assumes that, for large tracts, errors in measurement of areas below the datum plane are compensated by errors of a similar magnitude above the datum plane.) Small tracts in rough topography should be measured on controlled maps. Measurement techniques are similar in both cases, so the procedures outlined for measuring area on photographs generally apply to map determinations.

Devices for area measurement.—The principal devices for area measurement are polar planimeters, transects, and dot grids.

The planimeter is relatively expensive and its use somewhat tedious. The pointer is carefully run clockwise around the boundaries of an area two or more times (for an average reading). From the vernier scale, the area is read in square inches and then converted to the desired units, usually acres, on the basis of photo or map scale.

The transect method is analogous to determining forest area by a strip cruise in which the chainage encountered in each forest type is recorded. An engineer's scale is alined on the photographs to cross topography and drainage at approximately right angles. The length of each type along the scale is recorded to the nearest tenth of an inch. Proportions for each type are developed by relating the total measure of that type to the total linear measure. For example, if six equally spaced parallel lines 6 inches long are tallied on a given photograph, the total transect length is 36 inches. If hardwoods are intercepted for a total measure of 7.2 inches, this particular type would be assigned an acreage equivalent to 7.2÷36, or 20 percent of the total area. The transect method is simple and requires a minimum of equipment. For making rough area estimates on photo index sheets, special transparent overlays for location of transect lines can be improvised (*9*).

Use of a dot grid is the preferred method for determining area on aerial photographs. A dot grid is a transparent overlay with dots systematically arranged on a grid pattern. In use, the grid is alined with a straight-line feature to avoid positioning bias, and then dots are tallied for each forest type (fig. 21). Type areas are calculated by proportions: the number of dots on a given type divided by the total number of dots counted yields a percentage value that is multiplied by the total area to obtain the acreage of the type. If total acreage is not known, the number of acres per square inch is determined. This figure is then divided by the number of dots per square inch to find the acreage represented by each dot.

Intensity of dot sampling.—The number of dots that must be counted for a given accuracy depends upon the estimated proportion of the total area occupied by the most important classification to be recognized. For example, suppose area breakdowns are needed for 10 square miles photographed at a scale of 1:15,840. Estimated proportions of each area classification are as follows: forest, 25 percent; agricultural lands, 60 percent; urban areas, 10 percent; and rivers and lakes, 5 percent. If the most important category is agricultural land, the dot grid intensity would be calculated on this basis. If the population being sampled is large, the number of samples may be computed by a formula based on the binomial distribution:

$$n=p(1-p)\left[\frac{t}{E}\right]^2$$

Where: n=total number of samples (dots) to be counted.

p=estimated proportion of the total area in the most important type classification (0.60 in this case).

t=a constant denoting the reliability of the estimate or level of statistical significance (the value 1.96 used here denotes a statistical probability of being correct 95 times in 100).

E=maximum permissible error, expressed as a percent of total area. (In this case, ±2 percent or 0.02.)

Substituting the above values, we get:

$$n=0.60(1-0.60)\left[\frac{1.96}{0.02}\right]^2=2{,}305 \text{ dots}$$

Thus if we are correct in the assumption that the true percentage of agricultural land is 60, then 2,305 dots should be spaced over the total area to insure a 95-percent probability of obtaining an estimated proportion lying between 58 and 62 percent. At the specified photo scale of 1:15,840, the total print area represented by 10 square miles would be 160 square inches. Therefore, the number of dots needed per square inch would be 2,305 ÷160, or about 14. Here, it would be most expedient to select a square-spaced grid having 16 dots per square inch.

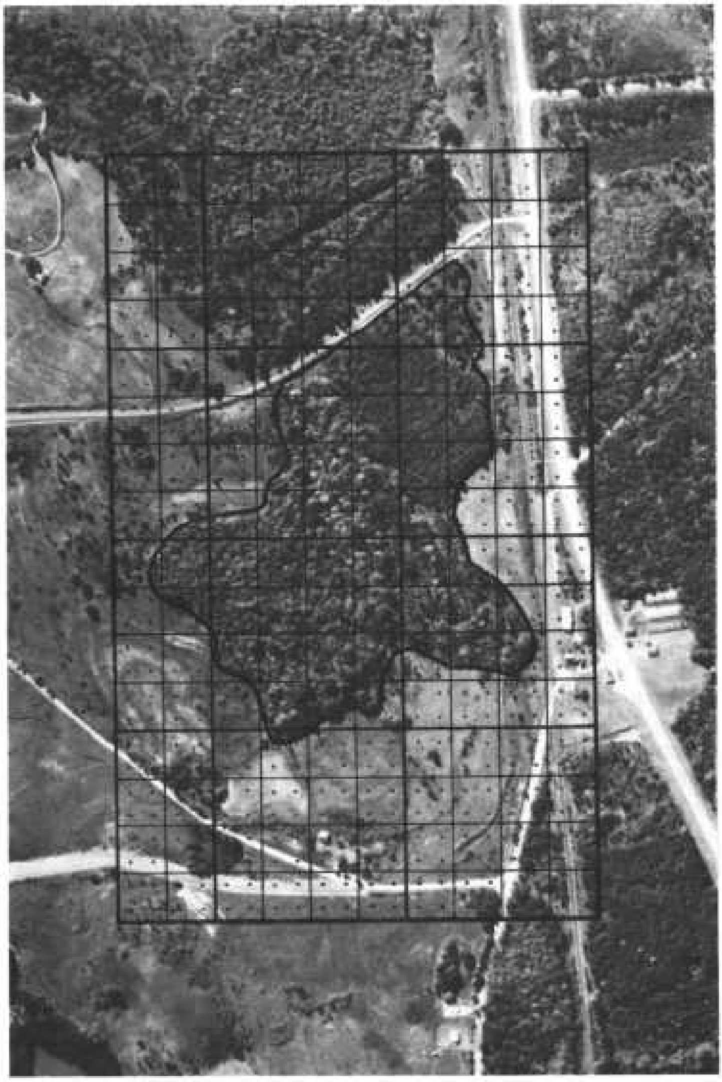

***Figure 21.*—Dot grid positioned over part of an enlarged USDA print for acreage determination. The delineated stand contains about 25 acres. Photo scale is 660 feet per inch.**

The principal drawback to the formula method is that a prior knowledge of p is required, which is actually the value being sought. By definition, however, p always lies between 0 and 1, and it can be shown that $p(1-p)$ reaches a maximum value of 0.25 when p is set at 0.50 or 50 percent. Therefore, the equation may be revised to read:

$$n=0.25\left[\frac{t}{E}\right]^2$$

And, substituting values from the previous solution:

$$n=0.25\left[\frac{1.96}{0.02}\right]^2=2{,}401 \text{ dots, an increase of 96 dots}$$
over the first estimate.

A grid with 16 dots per square inch will still be adequate for the desired degree of accuracy ($16\times160=2{,}560$ dots).

For areas of 1,000 acres or less, grids with closely spaced dots are needed. Grids with 64 dots per square inch are commonly used with 1:20,000 photographs. As 1 square inch equals 63.77 acres at photo scale, each dot represents 0.996 acres. For 1:15,840 photography (40 acres per square inch), grids having 40 dots per square inch are available. It is not essential, of course, that a separate grid be used for each photo scale or that the number of dots per square inch be equal to the acreage per square inch. Wherever feasible, the preceding equation should be used to determine the grid intensity.

TREE HEIGHT, CROWN DIAMETER, AND CROWN CLOSURE

Tree Height

Tree heights are commonly determined on aerial photographs by measuring either stereoscopic parallax or shadow lengths. Though more difficult for the beginner, the parallax method is faster, requires fewer calculations, and is more adaptable to a variety of stand conditions. Anyone who can use a stereoscope can train himself to measure stereoscopic parallax, and even the occasional interpreter will find this method of measuring heights advantageous.

Shadow-length measurements are reliable only in open-grown stands where individual shadows fall on level ground. Accurate measurement is almost impossible in dense, irregular stands or on slopes. Furthermore, the conversion of shadow length to tree height is complex in comparison to the conversion of parallax measurements. For these reasons only the parallax method will be discussed. Foresters interested in details of shadow-height calculations should refer to Johnson's article (*8*), which includes a special form for making tree-height conversions.

The concept of parallax.—The Manual of Photogrammetry (*1*) defines parallax as "the apparent displacement of the position of a body with respect to a reference point or system, caused by a shift in the point of observation." In measuring object heights on stereoscopic pairs of aerial photographs, two types of parallax must be measured or approximated—the absolute and the differential. The absolute stereoscopic parallax of a point is "the algebraic difference, parallel to the air base, of the distances of the two images from their respective principal points" (*18*). The parallax difference, or differential parallax, of an object being measured for height determination is the difference in the absolute stereoscopic parallax at the top and the base of the object, measured parallel to the air base or flight line.

The formula for converting parallax measurements to tree height on aerial photographs is:

$$h=\frac{H\times dP}{P+dP}$$

where h = height of object
H = altitude of aircraft above ground datum
P = absolute stereoscopic parallax at base of object being measured
dP = differential parallax

If object heights are to be determined in feet, the height of the aircraft (H) must also be in feet. Absolute stereoscopic parallax (P) and differential parallax (dP) must be expressed in the same units; ordinarily, these units will be thousandths of inches or hundredths of millimeters.

The height of the aircraft above ground datum is calculated from the basic scale formula, transposed to the more convenient form: Flight altitude (H) = focal length $\times$ scale denominator. With photographs of 1:20,000 scale and a camera of 8.25-inch focal length, the flight altitude would be $0.6875\times 20{,}000=13{,}750$ feet.

In flat terrain, the average photo base length is ordinarily substituted as the absolute stereoscopic parallax (P). If the ground elevation at the base of the tree being measured differs from the elevation of the principal points by more than 200 or 300 feet, however, the following method (*17*) should be used to calculate a new value for P:

1. Orient the stereo-pair with flight lines superimposed and images separated about 2.2 inches. Clip down photographs.
2. Measure the distance between the two principal points to the nearest 0.01 inch with an engineer's scale.
3. Measure the distance between corresponding images on the two photographs at or near the base of the tree to the nearest 0.01 inch.
4. Subtract (3) from (2) to obtain the absolute stereoscopic parallax at the base of the tree.

Differential parallax (dP) is usually measured stereoscopically with either a parallax wedge or parallax bar, employing the "floating mark" principle. Such instruments are discussed in the section that follows. The concept of differential parallax can be illustrated by direct measurement of severely displaced images such as in the large-scale stereogram of a water tank in figure 22. With a photo scale of 1:7,800 and a camera focal length of 6 inches, flight altitude above ground (H) is computed as $0.5\times 7{,}800$ or 3,900 feet. Average photo base length (P) for the stereo-pair is 3.70 inches.

Absolute stereoscopic parallax at the base and top of the water tank is measured parallel to the line of flight with an engineer's scale; the difference ($2.27-2.13$ inches) is dP, the differential parallax of the displaced images. As the tank is somewhat tapered in form, measurements were made at the midpoint of the base and vertically above this position at the center of the top. Substituting in the parallax formula:

$$\text{Height of tank } (h)=\frac{3{,}900\times 0.14}{3.70+0.14}=\frac{546.00}{3.84}=142 \text{ feet}$$

Parallax wedges.—Parallax wedges are usually printed on transparent film or glass. The basic design consists of two rows of dots or graduated lines beginning about 2.5 inches apart and converging to about 1.8 inches apart. The graduations on each line are calibrated for making parallax readings to the nearest 0.002 inch. The "training wedge" in figure 23 is graduated for reading to the nearest 0.01 inch only.

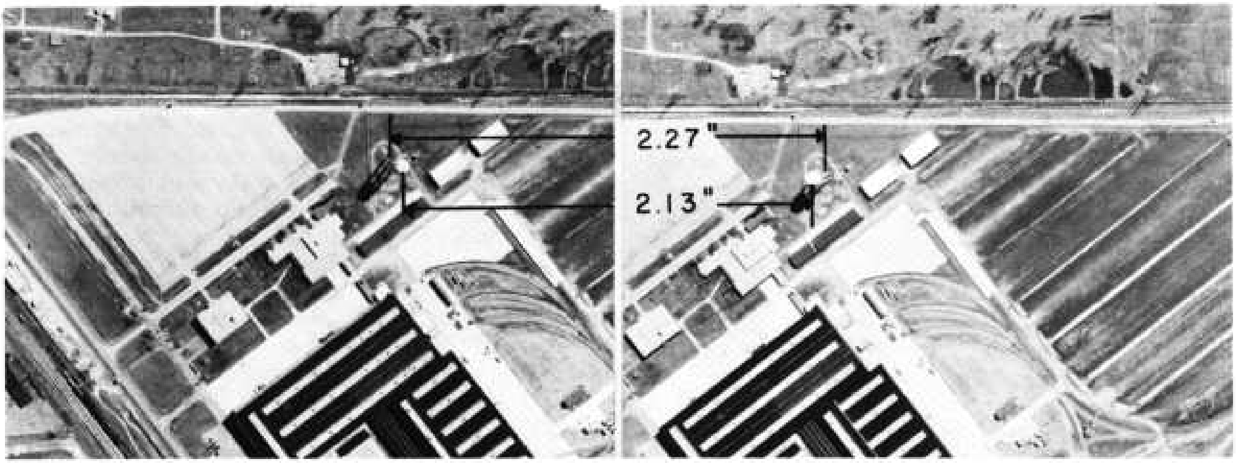

Figure 22.—Large-scale stereogram showing an industrial plant and heavily displaced water tank. Measurements of stereoscopic parallax shown can be used to determine height of the tank above ground. (Courtesy of Abrams Aerial Survey Corporation.)

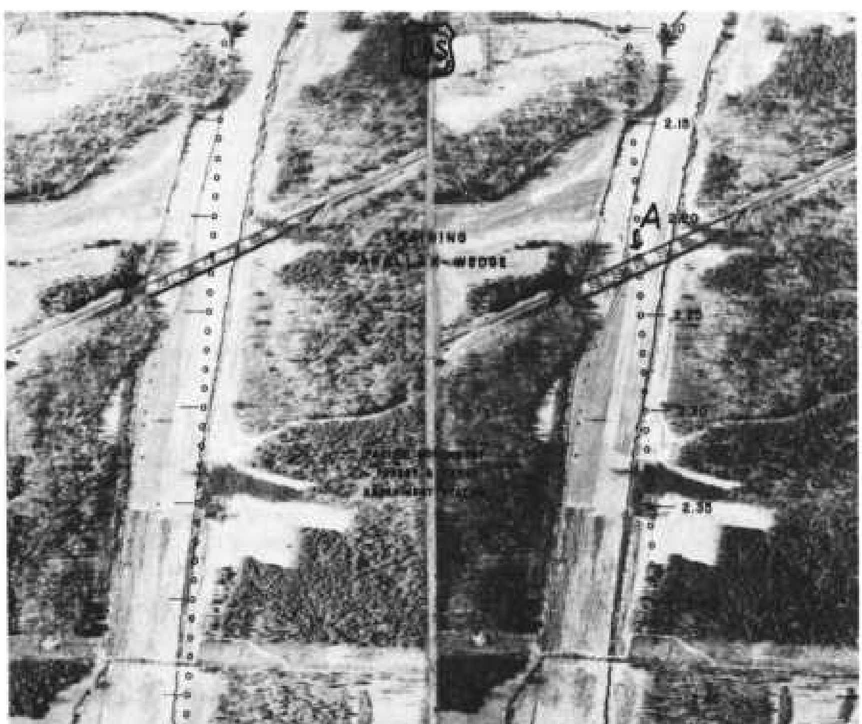

Figure 23.—Parallax wedge correctly oriented over a large-scale stereogram of a railroad trestle. Graduations on right-hand row of dots refer to separation of the converging lines in inches. (Courtesy of Abrams Aerial Survey Corporation.)

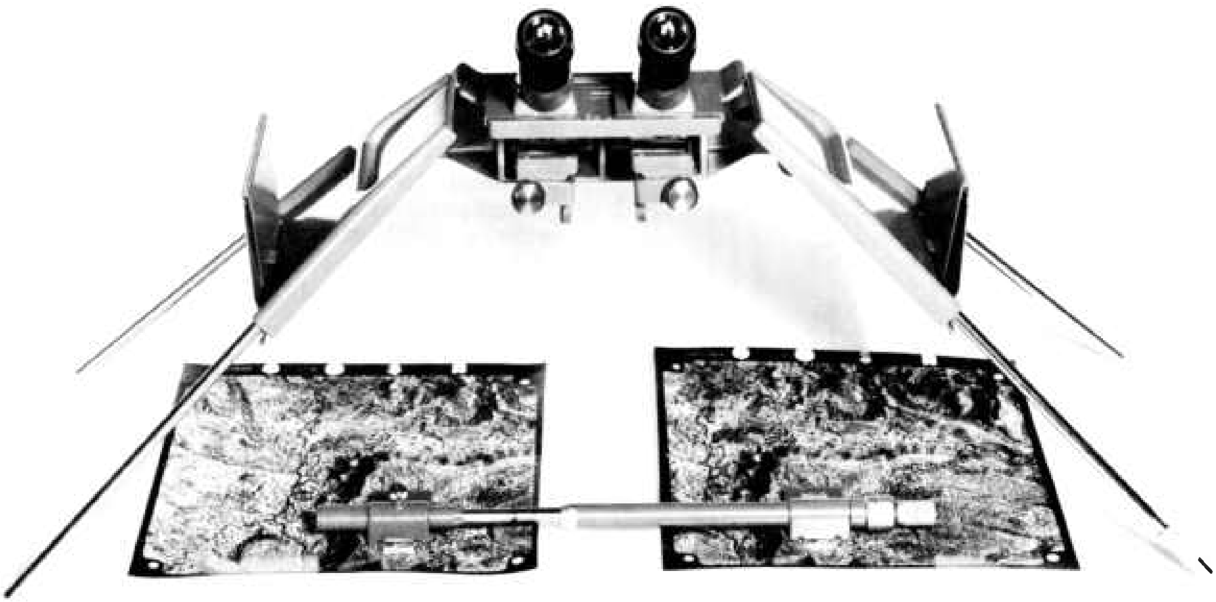

***Figure 24.*—Modern mirror stereoscope with inclined magnifying binoculars. Positioned across the two photographs is a parallax bar (stereometer) for measuring heights of objects. (Courtesy of Wild-Heerbrugg Instruments, Inc.)**

The parallax wedge is placed over the stereoscopic image with the converging lines perpendicular to the line of flight and adjusted until a single fused line of dots or graduations is seen sloping downward through the stereoscopic image. If the photo images are separated by exactly 2 inches, a portion of the parallax wedge centering around the 2-inch separation of converging lines will fuse and appear as a single line. The line will appear to split above and below this section. Using the fused line of graduations, the differential parallax is obtained by counting the number of dots or intervals between the point where a graduation appears to rest on the ground and the point where a graduation appears to "float" in the air at the same height as the top of the object. In figure 23, for example, the dot resting on top of the railroad trestle yields a reading of 2.22 inches. When this value is subtracted from a ground reading of 2.26 inches, dP is determined as 0.04 inches. If flight altitude (H) of 4,000 feet and a photo base length of 3.56 inches, the parallax formula yields:

$$\text{Height of trestle } (h)=\frac{4{,}000\times 0.04}{3.56+0.04}=\frac{160.00}{3.60}=44 \text{ feet}$$

The interpreter should remember that the degree of stereoscopic parallax normally encountered on 1:12,000 to 1:20,000 USDA photographs is much less than that illustrated here. Nevertheless, the principle and the methods of measurement are exactly the same. Where P is large in relation to dP, tables 2 and 3 can be used as shortcut approximations in converting parallax measurements to object heights on USDA photographs.

The parallax bar.—This instrument is more expensive than the parallax wedge and yields results of comparable accuracy. But many interpreters prefer the parallax bar because the floating dot is movable and thus easier to place on the ground and at crown levels. A parallax bar designed to measure heights with a mirror stereoscope is shown in figure 24.

The bar has two lenses attached to a metal frame that houses a vernier and a graduated metric scale. The left lens contains the fixed reference dot; the dot on the right lens can be moved laterally by means of the vernier. The bar is placed over the stereoscopic image parallel to the line of flight. The right-hand dot is moved until it fuses with the reference dot and appears to rest on the ground at the base of the tree. The vernier reading is recorded to the nearest 0.01 millimeter. The vernier is then turned until the fused dot appears to "float" at treetop level, and a second reading recorded. The difference between the readings is the parallax difference (dP) in millimeters. This value can be substituted in the parallax formula without conversion if the absolute parallax (P) is also expressed in millimeters.

Accuracy of height measurements.—Accuracy in

TABLE 2.—*Parallax-wedge conversion factors for wedges reading to 0.002-inch parallax (dP)*[1]

Photo base (*P*) (inches)	Object height in feet per 0.002 inch of *dP*, at flight altitudes of —				
	6,000 feet	8,000 feet	10,000 feet	12,000 feet	14,000 feet
2.6	4.6	6.1	7.7	9.2	10.8
2.7	4.4	5.9	7.4	8.9	10.4
2.8	4.3	5.7	7.1	8.6	10.0
2.9	4.1	5.5	6.9	8.3	9.6
3.0	4.0	5.3	6.7	8.0	9.3
3.1	3.9	5.2	6.4	7.7	9.0
3.2	3.7	5.0	6.2	7.5	8.7
3.3	3.6	4.8	6.1	7.3	8.5
3.4	3.5	4.7	5.9	7.0	8.2
3.5	3.4	4.6	5.7	6.8	8.0
3.6	3.3	4.4	5.6	6.7	7.8
3.7	3.2	4.3	5.4	6.5	7.6
3.8	3.1	4.2	5.3	6.3	7.4
3.9	3.1	4.1	5.1	6.1	7.2
4.0	3.0	4.0	5.0	6.0	7.0

[1] To use table, measure parallax difference (*dP*) of object to nearest 0.002-inch (as 0.016 or 8 dot intervals on wedge). If average photo base (*P*) is 3.6 inches and flight altitude is 14,000 feet, the table value of 7.8 is multiplied by the 8 dot intervals for an object height of 62 feet.

TABLE 3.—*Parallax-bar conversion factors for use with devices reading to 0.01-mm. parallax (dP)*[1]

Photo base (*P*) (inches)	Object height in feet per millimeter of dP at flight altitudes of—				
	6,000 feet	8,000 feet	10,000 feet	12,000 feet	14,000 feet
2.6	90	119	149	179	209
2.7	86	115	144	172	201
2.8	83	111	139	166	194
2.9	80	107	134	161	187
3.0	78	104	130	155	181
3.1	75	100	125	151	176
3.2	73	97	122	146	170
3.3	71	94	118	142	165
3.4	69	92	114	137	160
3.5	67	89	111	133	156
3.6	65	87	108	130	152
3.7	63	84	105	126	147
3.8	62	82	103	123	144
3.9	60	80	100	120	140
4.0	58	78	97	117	136

[1] To use table, measure parallax difference (*dP*) of object to nearest hundredth of a millimeter (as 0.57 mm., for example). If average photo base (*P*) is 3.1 inches and flight altitude is 12,000 feet, the table value of 151 is multiplied by 0.57 for an object height of 86 feet.

measuring total heights of trees and stands depends upon a number of factors, not the least of which is the interpreter's ability to determine stereoscopic parallax. Usually interpreters can detect differences in parallax of about 0.002 inch, or 0.05 mm., and this graduation interval is used on most parallax wedges.

The interpreter who can detect a difference of 0.002 inch of stereoscopic parallax will be able to stratify forest stands into 10-foot total height classes on contact prints of 1:15,840 to 1:20,000 scales (*18*). Greater accuracy may be possible in flat terrain where photo scale changes are not pronounced and less skill is required in selecting the point for the base parallax reading. The ground parallax must be read on the same contour as the base of the tree.

The interpreter should consider the following points to improve accuracy in height measurement:

1. In rough terrain, a new photo scale and flight altitude should be calculated for each overlap. For stands on high ridges or in deep ravines, it is better to calculate new values for absolute stereoscopic parallax than to use the average photo base length.
2. Once a pair of photographs have been alined for stereo-viewing, they should be fastened down. A slip of either photograph between the parallax reading at the base and the top of a tree may cause highly inaccurate height readings.
3. To avoid single measurements of high variability, several measurements should be made of the same tree or stand and the results averaged.

Tree Crown Diameter

For most conifers and many hardwoods, tree crown diameter is related to stem diameter. It is thus a useful photographic measurement when estimating individual tree volumes or stand-size classes. Actual determination of crown diameter is a distance measurement, somewhat complicated by the small sizes of tree images and the effects of crown shadows.

Crown diameters are measured with either wedges or dot-type scales reading in thousandths of an inch. With a crown wedge, the diverging lines are placed tangent to both sides of the crown for making the reading. Dot-type scales have circles of graduated sizes for direct comparison with tree crowns (fig. 25). For converting measurements, the scale of photography is calculated in feet per thousandth of an inch. At 1:20,000, each 0.001 inch of crown measure equals 1.667 feet. A reading of 0.010 inch would imply a crown diameter of 17 feet (table 4).

Tree crowns are rarely circular, but, because individual limbs are often invisible on aerial photographs, they usually appear roughly circular or elliptical. Since only the parts visible from above can be evaluated, photo measures of crown diameter are often lower than ground checks of the same trees. Nevertheless, most interpreters can determine average crown diameter with reasonable precision if they take several readings.

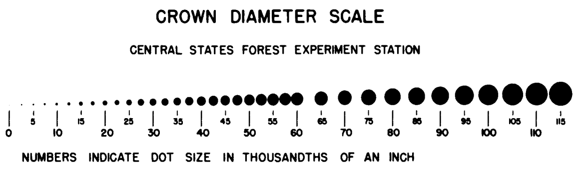

***Figure 25.*—Dot-type scale for measuring crown diameters. Such scales are usually printed on transparent film.**

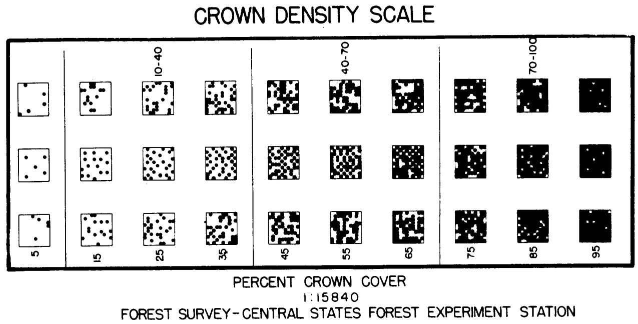

***Figure 26.*—Density scale for comparison with photo images in estimating crown closure percent.**

Obviously, crown diameter measurements of individual trees are most accurate in open-grown stands. In dense stands, measurements are generally confined to determination of an average for the dominant trees. Crowns of mature conifers can usually be classified into 5-foot classes without difficulty (*18*).

Tree Crown Closure

Crown closure percent, also referred to as crown density, is the proportion of the forest canopy occupied by trees. Crown density may refer to all crowns in the stand regardless of canopy level or only to the dominants. Estimates are purely ocular, and stands are commonly grouped into 10-percent density classes. Printed density scales (fig. 26) may aid the interpreter, though the patterns of black dots on a white background bear little resemblance to photographic images of trees. Comparative stereograms illustrating various stand densities have also proved useful (fig. 27).

Evaluation of crown closure is much more subjective than the determination of tree height or crown diameter. Actual measurement is virtually impossible on most USDA photographs, and accuracy is thus dependent on the interpreter's judgment. Inexperienced interpreters tend to overestimate closure by ignoring small stand openings or including portions of crown shadows. Devices for checking closure on the ground fail to provide estimates that are truly comparable to those made on vertical photographs. Thus the neophyte must rely on practice, checked by skilled interpreters, to develop proficiency.

Crown closure is useful because of its relation to stand volume per acre. It is applied in lieu of basal area or number of trees per acre, as these cannot be accurately determined on available photography. Measurements of crown diameter and estimates of closure should always be made under the stereoscope.

Tree counts.—Complete tallies of individual trees can seldom be made accurately on available USDA photographs. In dense stands, suppressed trees and many intermediates cannot be seen. Clumps of two or three trees often appear as single

TABLE 4.—*Actual crown widths for various photo-crown widths and photo scales*

Photo crown width (thousandths of an inch)	1:10,000 or 833 ft./in.	1:12,000 or 1,000 ft./in.	1:15,840 or 1,320 ft./in.	1:18,000 or 1,500 ft./in.	1:20,000 or 1,667 ft./in.	1:24,000 or 2,000 ft./in.
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
2.5	2	3	3	4	4	5
5.0	4	5	7	8	8	10
7.5	6	8	10	11	13	15
10.0	8	10	13	15	17	20
12.5	10	13	17	19	21	25
15.0	12	15	20	23	25	30
17.5	15	18	23	26	29	35
20.0	17	20	26	30	33	40
22.5	19	23	30	34	38	45
25.0	21	25	33	38	42	50
27.5	23	28	36	41	46	55
30.0	25	30	40	45	50	60
32.5	27	33	43	49	54	----------
35.0	29	35	46	53	58	----------
37.5	31	38	50	56	63	----------
40.0	33	40	53	60	67	----------
42.5	35	43	56	----------	----------	----------
45.0	37	45	59	----------	----------	----------
47.5	40	48	63	----------	----------	----------
50.0	42	50	66	----------	----------	----------

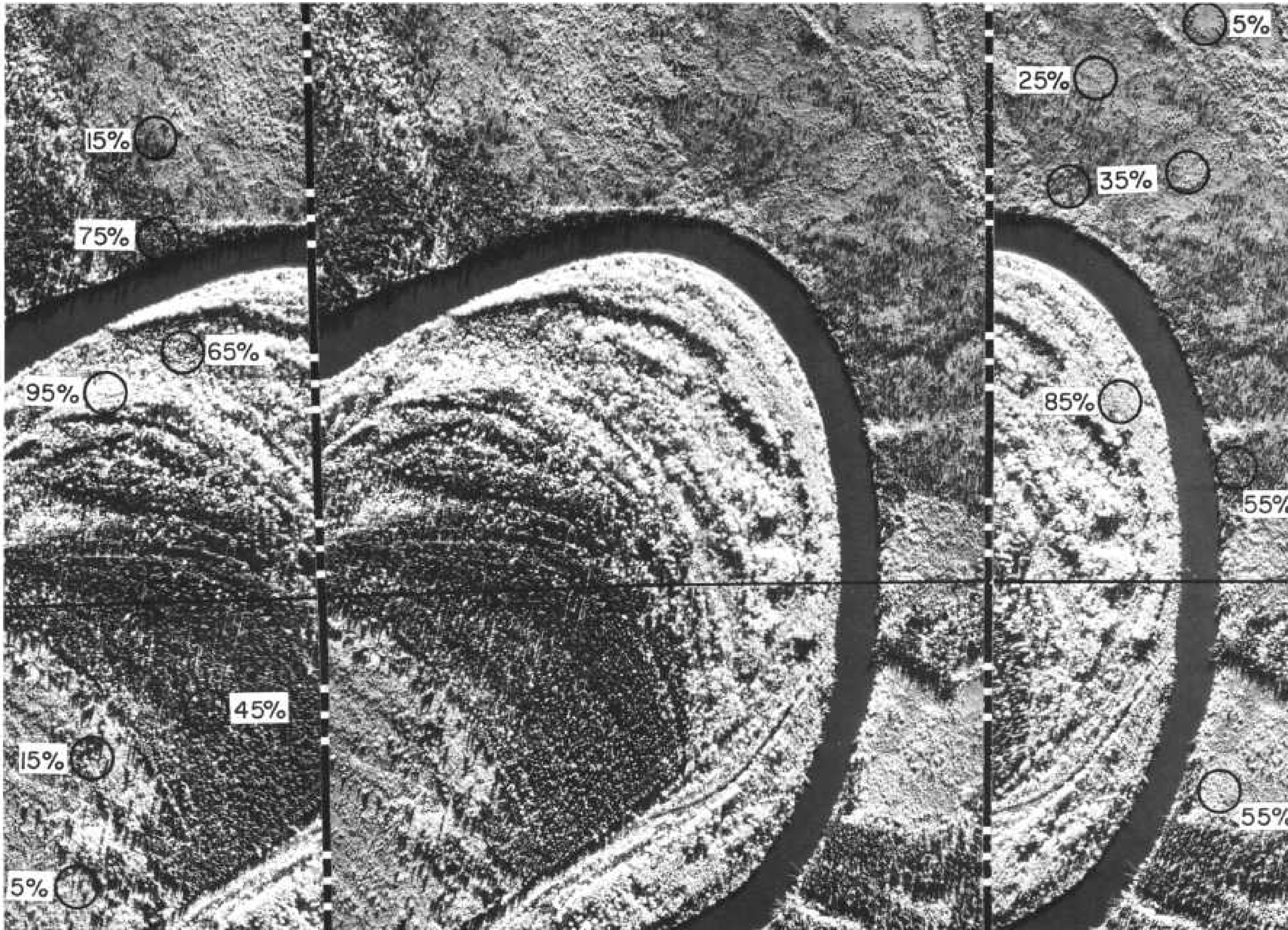

Figure 27.—Infrared stereo-triplet from central Alaska, showing estimates of tree crown closure. Scale is about 420 feet per inch; each circle represents approximately 0.25 acre. The solid black line indicates the path of the aircraft.

crowns, and ragged individual crowns may look like two trees. Only in even-aged, open-grown forests can all trees in a stand be separated. Counting all trees on a plot is tedious, and this measure of density is seldom used. Where large-scale photographs are available (1:1,000 to 1:5,000), individual-tree counts may be much more reliable.

AERIAL CRUISING

Individual Tree Volumes

Ordinary tree volume tables can be easily converted to aerial volume tables when correlations can be established between tree crown diameters and stem diameters (*10*). The photographic determinations of crown diameter and total tree height are merely substituted for the usual field measures of stem diameter (d.b.h.) and merchantable height, respectively (fig. 28). Photographic measurements are usually limited to well-defined open-grown trees, and crown counts are required to obtain total volume for a given stand of timber.

The construction and application of aerial tree volume tables depends on a well-established relationship between photographic measures of crown diameter and ground determinations of tree d.b.h. Such relationships can often be established for individual species or species groups, notably even-aged conifers in the middle diameter classes (*18*). By contrast, stem-crown diameter correlations rarely have been used for estimating volumes of mixed hardwoods.

The aerial tree table (table 5) provides volumes in terms of gross cubic feet. In making an aerial cruise, photographic measurements may include all trees on 0.2- to 1-acre circular plots, or stands may be delineated according to height classes for determination of the average tree per unit area. In the latter instance, a tree count must be made to obtain the total stand volume.

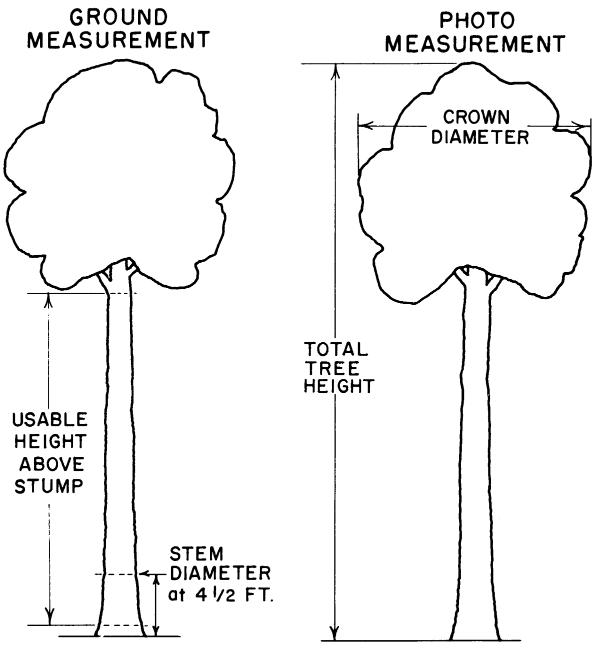

Figure 28.—**Comparison of ground and photographic measurements in the determination of individual tree volumes.**

In general, the individual-tree approach to aerial crusing is of limited value when the interpreter is restricted to use of 1:12,000 to 1:20,000 USDA photographs. At this scale, images are usually too small for accurate assessment of individual trees.

Stand Volume Per Acre

If recent photographs and reliable aerial stand-volume tables can be obtained, average stand volume per acre can be estimated with a minimum of field work. Estimates are made in terms of gross volume, as amount of cull or defect cannot be adequately evaluated. Even-aged stands of simple species structure are best suited for this type of estimating, especially if gross and net volumes are essentially identical. All-aged stands of mixed hardwoods are more difficult to assess, but satisfactory results can be obtained if field checks are made to adjust the photographic estimate of stand volume per acre and to determine allowance for defect. Though volumes from photographs cannot be expressed by species and diameter classes, total gross volumes for areas as small as 40 acres can be estimated within 10 to 15 percent of volumes derived from conventional ground cruises (*13*).

Most aerial stand-volume tables for mixed species are constructed in terms of cubic feet per acre. Tables for species in pure stands, such as Douglas-fir, may be expressed either in board feet or cubic feet per acre. Three photographic measurements of the dominant stand are generally required for entering an aerial stand volume table: average total height, crown diameter, and crown closure percent.

Aerial volume tables have been constructed for many of the important timber associations in the United States. Included here are tables for Douglas-fir (table 6), Rocky Mountain conifers (table 7), and Kentucky hardwoods (table 8). Composite tables, applicable in mixed stands, are presented for northeast Mississippi (table 9) and for northern Minnesota (table 10). Crown diameter was eliminated as a variable in tables 6 and 10.

TABLE 5.—*Volumes of individual second-growth southern pines* [1]

Crown diameter class (feet)	Total tree height, in feet						
	50	60	70	80	90	100	110
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
10	9. 5	11. 5	12. 5	15. 0	17. 5	19. 5	-----
12	12. 5	14. 5	16..5	18. 0	20. 5	22. 5	-----
14	15. 0	17. 0	19. 0	23. 5	25. 0	27. 5	30. 5
16	17. 5	20. 5	24. 0	27. 5	30. 5	33. 0	36. 0
18	------	23. 5	27. 0	30. 5	34. 5	38. 0	42. 5
20	------	28. 0	33. 5	36. 0	40. 0	45. 5	49. 0
22	------	32. 5	37. 0	42. 5	46. 5	52. 0	57. 5
24	------	37. 0	42. 5	48. 5	54. 5	60. 0	66. 0
26	------	42. 5	47. 5	54. 0	61. 0	67. 5	75. 5
28	------	------	53. 0	60. 5	70. 5	76. 0	83. 0
30	------	------	60. 5	68. 0	78. 0	85. 5	94. 5

[1] Based on 342 trees in Arkansas, Lousiana, and Mississippi. Gross volumes are inside bark and include the merchantable stem to a variable top averaging 6 inches i.b. Reprinted from (*4*).

One of the several procedures for making aerial volume estimates is as follows:

1. Outline tract boundaries on the photographs, utilizing the effective area of every other print in each flight line. This assures stereoscopic coverage of the area on a minimum number of photographs and avoids duplication of measurements.
2. Delineate all forest types. Except where type lines define stands of relatively uniform stocking and total height, they should be further broken down into homogeneous units so that measures of height, density, and crown diameter will apply to the entire unit. Generally it is unnecessary to recognize stands smaller than 5 to 10 acres.
3. Determine the acreage of each condition class with dot grids. This determination can often be made on contact prints.
4. By stereoscopic examination, measure the variables for entering the aerial stand volume table. From the table, obtain the average volume per acre for each condition class.
5. Multiply gross volumes per acre from the table by condition class areas to determine gross volume.
6. Add class volumes for the total gross volume on the tract.

A practical application is illustrated by the stereogram in figure 29 and the corresponding cordwood volume summary. In this particular inventory, hardwood components in each stand were ignored, and estimates were derived only for pine timber. The aerial cruise, fortified by fre-

TABLE 6.—*Aerial stand volume per acre values* [1] *for even-aged Douglas-fir in the Pacific Northwest*

Stand height [2] (feet)	Crown closure percent [3]								
	15	25	35	45	55	65	75	85	95
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
40	500	800	1, 100	1, 300	1, 400	1, 500	1, 500	1, 400	1, 300
50	700	1, 100	1, 500	1, 800	2, 000	2, 100	2, 200	2, 100	2, 000
60	900	1, 500	2, 000	2, 400	2, 700	2, 900	3, 000	2, 900	2, 800
70	1, 200	1, 900	2, 500	3, 100	3, 400	3, 700	3, 900	3, 900	3, 800
80	1, 400	2, 400	3, 100	3, 800	4, 300	4, 600	4, 800	4, 900	4, 900
90	1, 700	2, 800	3, 800	4, 500	5, 200	5, 600	5, 900	6, 100	6, 100
100	2, 100	3, 300	4, 500	5, 400	6, 100	6, 700	7, 200	7, 400	7, 500
110	2, 400	3, 900	5, 200	6, 300	7, 200	7, 900	8, 500	8, 800	9, 000
120	2, 800	4, 500	6, 000	7, 300	8, 300	9, 200	9, 900	10, 300	10, 600
130	3, 100	5, 100	6, 800	8, 300	9, 500	10, 600	11, 400	12, 000	12, 400
140	3, 500	5, 700	7, 700	9, 400	10, 800	12, 100	13, 000	13, 800	14, 300
150	4, 000	6, 400	8, 600	10, 500	12, 200	13, 600	14, 800	15, 700	16, 300
160	4, 400	7, 100	9, 600	11, 800	13, 600	15, 300	16, 600	17, 700	18, 500
170	4, 900	7, 900	10, 600	13, 000	15, 200	17, 000	18, 500	19, 800	20, 800
180	5, 400	8, 700	11, 700	14, 400	16, 800	18, 800	20, 600	22, 000	23, 200
190	5, 900	9, 500	12, 800	15, 800	18, 400	20, 800	22, 700	24, 400	25, 700
200	6, 400	10, 400	14, 000	17, 300	20, 200	22, 800	25, 000	26, 900	28, 400
210	7, 000	11, 300	15, 200	18, 800	22, 000	24, 900	27, 400	29, 500	31, 300
220	7, 500	12, 200	16, 500	20, 400	23, 900	27, 100	29, 800	32, 200	34, 200
230	8, 100	13, 200	17, 800	22, 000	25, 900	29, 300	32, 400	35, 100	37, 300
240	8, 700	14, 200	19, 200	23, 800	28, 000	31, 700	35, 100	38, 000	40, 600
250	9, 400	15, 200	20, 600	25, 600	30, 100	34, 200	37, 900	41, 100	43, 900
260	10, 000	16, 300	22, 100	27, 400	32, 300	36, 700	40, 800	44, 300	47, 400

[1] Gross volume, in trees 5.0 inches and larger, from stump to top limit of 4.0 inches diameter inside bark. Reprinted from (*15*).
[2] Average height of dominants and codominants as measured in the field.
[3] Average estimates of several experienced interpreters includes all trees in the major canopy (occasionally excludes small trees definitely below the general canopy).

TABLE 7.—*Aerial volume per acre for Rocky Mountain conifers* [1]

4- TO 7-FOOT CROWN DIAMETER

Average stand height (feet)	Crown closure percent 5	15	25	35	45	55	65	75	85	95
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
30	--------	100	300	450	550	650	750	850	1,000	1,150
35	--------	200	400	550	650	750	850	1,000	1,200	1,400
40	--------	300	500	650	750	850	1,000	1,150	1,400	1,650
45	50	400	600	750	850	950	1,100	1,300	1,550	1,800
50	100	500	700	850	1,000	1,150	1,350	1,600	1,850	2,100
55	200	600	850	1,050	1,200	1,400	1,600	1,850	2,100	2,350
60	350	800	1,100	1,350	1,600	1,800	2,000	2,250	2,500	2,750
65	500	1,050	1,400	1,700	1,950	2,150	2,350	2,550	2,800	3,050

8- TO 12-FOOT CROWN DIAMETER

Average stand height (feet)	5	15	25	35	45	55	65	75	85	95
30	--------	150	350	500	600	700	800	950	1,200	1,350
35	--------	250	450	600	750	850	950	1,100	1,300	1,500
40	--------	350	550	700	850	950	1,050	1,250	1,500	1,750
45	--------	400	650	800	950	1,100	1,250	1,450	1,700	1,950
50	100	500	700	950	1,100	1,250	1,450	1,700	1,950	2,150
55	300	700	900	1,100	1,300	1,500	1,750	2,000	2,225	2,500
60	450	900	1,200	1,500	1,750	1,950	2,150	2,350	2,550	2,650
65	700	1,200	1,600	1,900	2,100	2,300	2,500	2,700	2,900	3,100
70	900	1,600	2,000	2,300	2,500	2,700	2,850	3,000	3,200	3,300
75	1,200	2,000	2,400	2,700	2,850	3,000	3,200	3,400	3,600	3,800
80	1,700	2,500	2,800	3,100	3,300	3,450	3,600	3,800	4,000	4,200
85	2,200	3,000	3,300	3,550	3,750	3,950	4,150	4,350	4,550	4,750

13- TO 17-FOOT CROWN DIAMETER

Average stand height (feet)	5	15	25	35	45	55	65	75	85	95
30	--------	200	400	550	700	800	900	1,050	1,200	1,350
35	--------	300	500	700	800	900	1,050	1,200	1,500	1,700
40	--------	400	600	800	900	1,000	1,250	1,450	1,700	1,950
45	100	500	700	850	1,000	1,150	1,350	1,600	1,850	2,100
50	200	600	850	1,000	1,150	1,350	1,600	1,850	2,100	2,350
55	300	750	1,000	1,250	1,500	1,700	1,900	2,150	2,350	2,550
60	500	1,000	1,300	1,600	1,850	2,050	2,250	2,450	2,650	2,850
65	750	1,300	1,700	2,000	2,200	2,400	2,600	2,800	3,000	3,200
70	1,000	1,700	2,100	2,400	2,600	2,750	2,900	3,100	3,300	3,500
75	1,300	2,100	2,500	2,750	2,950	3,150	3,300	3,500	3,700	3,900
80	1,800	2,600	2,900	3,200	3,400	3,600	3,750	3,900	4,100	4,300
85	2,300	3,100	3,450	3,700	3,900	4,050	4,200	4,400	4,600	4,800
90	2,800	3,600	3,900	4,150	4,350	4,500	4,650	4,850	5,050	5,250
95	3,300	4,100	4,400	4,600	4,800	5,000	5,200	5,400	5,600	5,800
100	3,700	4,500	4,850	5,150	5,350	5,550	5,750	5,950	6,150	6,350

18- TO 22-FOOT CROWN DIAMETER

Average stand height (feet)	5	15	25	35	45	55	65	75	85	95
30	--------	300	500	700	800	900	1,050	1,200	1,400	1,600
35	--------	400	650	800	900	1,050	1,200	1,400	1,600	1,800
40	100	500	750	900	1,050	1,200	1,400	1,600	1,800	2,000
45	200	600	850	1,050	1,200	1,400	1,600	1,800	2,000	2,200
50	350	750	1,000	1,200	1,400	1,600	1,800	2,050	2,250	2,450
55	450	850	1,150	1,400	1,650	1,900	2,100	2,300	2,500	2,700
60	650	1,150	1,500	1,800	2,050	2,250	2,450	2,650	2,850	3,050
65	850	1,500	1,900	2,200	2,400	2,600	2,750	2,900	3,100	3,300
70	1,100	1,900	2,300	2,550	2,750	2,900	3,100	3,300	3,500	3,700
75	1,600	2,400	2,700	2,950	3,100	3,250	3,450	3,650	3,850	4,050
80	1,950	2,750	3,050	3,300	3,500	3,700	3,900	4,100	4,300	4,500
85	2,500	3,300	3,600	3,850	4,050	4,250	4,400	4,550	4,750	4,950
90	2,900	3,700	4,050	4,300	4,500	4,700	4,850	5,050	5,300	5,500
95	3,400	4,200	4,500	4,800	5,000	5,200	5,400	5,600	5,800	6,000
100	3,900	4,700	5,000	5,300	5,500	5,700	5,900	6,100	6,300	6,500
105	4,600	5,400	5,800	6,000	6,200	6,400	6,550	6,700	6,850	7,050
110	5,200	6,000	6,400	6,600	6,800	7,000	7,200	7,400	7,600	7,800

TABLE 7.—*Aerial volume per acre for Rocky Mountain conifers* [1]—Continued

23-FOOT AND LARGER CROWN DIAMETER

Average stand height (feet)	Crown closure percent									
	5	15	25	35	45	55	65	75	85	95
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
30	100	500	750	900	1, 050	1, 250	1, 450	1, 650	1, 900	2, 150
35	200	650	850	1, 050	1, 250	1, 450	1, 650	1, 850	2, 100	2, 350
40	300	750	1, 000	1, 200	1, 400	1, 600	1, 800	2, 050	2, 300	2, 550
45	400	850	1, 100	1, 350	1, 600	1, 800	2, 000	2, 250	2, 500	2, 750
50	550	1, 000	1, 300	1, 600	1, 850	2, 050	2, 250	2, 450	2, 650	2, 850
55	700	1, 200	1, 600	1, 900	2, 100	2, 300	2, 500	2, 700	2, 900	3, 100
60	850	1, 550	1, 950	2, 250	2, 450	2, 650	2, 850	3, 050	3, 250	3, 450
65	1, 200	1, 900	2, 300	2, 550	2, 750	2, 900	3, 100	3, 300	3, 500	3, 700
70	1, 550	2, 250	2, 650	2, 900	3, 100	3, 300	3, 450	3, 650	3, 850	4, 050
75	2, 050	2, 750	3, 050	3, 300	3, 500	3, 650	3, 800	4, 000	4, 200	4, 400
80	2, 450	3, 150	3, 450	3, 700	3, 900	4, 050	4, 200	4, 400	4, 600	4, 800
85	2, 900	3, 600	3, 950	4, 200	4, 400	4, 550	4, 700	4, 900	5, 100	5, 300
90	3, 400	4, 100	4, 400	4, 650	4, 850	5, 050	5, 250	5, 450	5, 650	5, 850
95	3, 850	4, 550	4, 850	5, 150	5, 350	5, 550	5, 750	5, 950	6, 150	6, 350
100	4, 400	5, 100	5, 400	5, 700	5, 900	6, 100	6, 250	6, 400	6, 600	6, 800
105	5, 100	5, 800	6, 100	6, 400	6, 550	6, 700	6, 850	7, 000	7, 150	7, 300
110	6, 600	6, 400	6, 700	6, 900	7, 050	7, 200	7, 350	7, 500	7, 700	7, 850
115	6, 150	6, 900	7, 200	7, 400	7, 600	7, 750	7, 900	8, 050	8, 200	8, 350

[1] Based on 168 field plots taken in southeastern Idaho, southwestern Wyoming, and northeastern Utah. Aggregate deviation: Table 1.5 percent low. Standard error of estimate: ± 48 percent of average plot volume. Reprinted from (*11*).

TABLE 8.—*Aerial volume per acre for Kentucky hardwoods* [1]

10- TO 14-FOOT AVERAGE CROWN DIAMETER

Average stand height (feet)	Crown closure percent								
	15	25	35	45	55	65	75	85	95
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
30	300	375	450	475	500	570	635	700	770
40	350	425	500	550	600	650	700	750	800
50	400	475	550	625	700	770	835	900	970
60	550	675	800	875	950	1, 035	1, 115	1, 200	1, 285
70	900	1, 075	1, 250	1, 325	1, 400	1, 470	1, 535	1, 600	1, 670
15- TO 19-FOOT AVERAGE CROWN DIAMETER									
30	350	400	450	500	550	620	685	750	820
40	400	450	500	575	650	720	785	850	920
50	450	525	600	675	750	835	920	1, 000	1, 085
60	600	725	850	950	1, 050	1, 100	1, 150	1, 200	1, 250
70	1, 000	1, 150	1, 300	1, 400	1, 500	1, 550	1, 600	1, 650	1, 700
80	1, 500	1, 625	1, 750	1, 825	1, 900	1, 970	2, 035	2, 100	2, 170
20- TO 29-FOOT AVERAGE CROWN DIAMETER									
40	500	625	750	850	950	1, 035	1, 115	1, 200	1, 285
50	600	750	900	1, 000	1, 100	1, 185	1, 270	1, 350	1, 435
60	900	1, 050	1, 200	1, 275	1, 350	1, 420	1, 485	1, 550	1, 620
70	1, 350	1, 475	1, 600	1, 675	1, 750	1, 820	1, 885	1, 950	2, 020
80	1, 750	1, 900	2, 050	2, 125	2, 200	2, 270	2, 335	2, 400	2, 470
90	2, 220	2, 360	2, 500	2, 575	2, 650	2, 720	2, 785	2, 850	2, 920
100	2, 700	2, 850	3, 000	3, 075	3, 150	3, 200	3, 250	3, 300	3, 350

TABLE 8.—*Aerial volume per acre for Kentucky hardwoods*[1]—Continued

30-FOOT AND LARGER AVERAGE CROWN DIAMETER

Average stand height (feet)	Crown closure percent								
	15	25	35	45	55	65	75	85	95
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
40	850	1, 025	1, 200	1, 275	1, 350	1, 420	1, 485	1, 550	1, 620
50	1, 050	1, 200	1, 350	1, 425	1, 500	1, 570	1, 635	1, 700	1, 770
60	1, 300	1, 450	1, 600	1, 650	1, 700	1, 785	1, 870	1, 950	2, 035
70	1, 700	1, 850	2, 000	2, 075	2, 150	2, 220	2, 285	2, 350	2, 420
80	2, 150	2, 275	2, 400	2, 500	2, 600	2, 670	2, 735	2, 800	2, 870
90	2, 600	2, 725	2, 850	2, 925	3, 000	3, 070	3, 135	3, 200	3, 270
100	3, 050	3, 175	3, 300	3, 375	3, 450	3, 500	3, 550	3, 600	3, 650
110	3, 600	3, 700	3, 800	3, 875	3, 950	4, 020	4, 085	4, 150	4, 220

[1] Gross volumes include the merchantable stems of all trees 5 inches d.b.h. and larger to a 4-inch top diameter i.b. Expanded from (*14*) by linear interpolation.

TABLE 9.—*Composite aerial volume per acre for northeast Mississippi*[1]

10-FOOT AVERAGE CROWN DIAMETER

Average stand height (feet)	Crown closure percent								
	15	25	35	45	55	65	75	85	95
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
30	190	310	430	560	690	810	940	1, 060	1, 180
40	230	380	530	690	840	990	1, 140	1, 300	1, 450
50	260	440	620	800	980	1, 150	1, 330	1, 510	1, 680
60	300	500	690	890	1, 090	1, 290	1, 490	1, 680	1, 880
70	340	570	800	1, 030	1, 260	1, 490	1, 720	1, 950	2, 180
80	380	640	890	1, 140	1, 400	1, 650	1, 910	2, 160	2, 420
15-FOOT AVERAGE CROWN DIAMETER									
30	210	350	500	640	780	930	1, 070	1, 220	1, 360
40	260	430	610	780	950	1, 130	1, 300	1, 480	1, 650
50	310	510	730	930	1, 140	1, 350	1, 550	1, 770	1, 970
60	360	590	830	1, 070	1, 300	1, 550	1, 780	2, 030	2, 260
70	400	660	940	1, 200	1, 460	1, 740	2, 000	2, 280	2, 540
80	440	740	1, 040	1, 330	1, 620	1, 930	2, 220	2, 530	2, 820
90	480	800	1, 140	1, 450	1, 770	2, 100	2, 420	2, 760	3, 070
20-FOOT AVERAGE CROWN DIAMETER									
40	270	450	630	820	1, 000	1, 190	1, 370	1, 550	1, 720
50	320	540	750	970	1, 190	1, 410	1, 630	1, 840	2, 040
60	360	610	860	1, 110	1, 360	1, 600	1, 850	2, 100	2, 330
70	410	680	960	1, 240	1, 520	1, 800	2, 080	2, 360	2, 610
80	450	760	1, 070	1, 380	1, 690	2, 000	2, 310	2, 620	2, 900
90	500	840	1, 190	1, 530	1, 870	2, 220	2, 560	2, 900	3, 220
100	540	920	1, 290	1, 670	2, 040	2, 410	2, 790	3, 160	3, 500
25-FOOT AVERAGE CROWN DIAMETER									
50	320	550	770	1, 000	1, 220	1, 450	1, 670	1, 900	2, 120
60	370	620	880	1, 130	1, 390	1, 650	1, 900	2, 160	2, 410
70	410	700	980	1, 270	1, 550	1, 840	2, 130	2, 410	2, 700
80	460	780	1, 100	1, 420	1, 740	2, 060	2, 380	2, 700	3, 020
90	510	860	1, 220	1, 570	1, 930	2, 280	2, 640	2, 990	3, 350
100	550	940	1, 320	1, 710	2, 090	2, 480	2, 860	3, 250	3, 630

[1] Gross volumes are inside bark and include the merchantable stem to a variable top not smaller than 3 inches i.b. Reprinted from (*3*).

TABLE 10.—*Composite aerial volume per acre*[1] *for northern Minnesota*[2]

Average total height (feet)	Crown closure percent									
	5	15	25	35	45	55	65	75	85	95
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
30	40	120	200	280	360	440	520	600	680	760
35	80	190	300	410	520	630	740	850	960	1, 070
40	180	310	440	570	700	830	960	1, 090	1, 220	1, 350
45	460	590	720	850	980	1, 110	1, 240	1, 370	1, 500	1, 630
50	740	870	1, 000	1, 130	1, 260	1, 390	1, 520	1, 650	1, 780	1, 910
55	1, 020	1, 150	1, 280	1, 410	1, 540	1, 670	1, 800	1, 930	2, 060	2, 190
60	1, 300	1, 430	1, 560	1, 690	1, 820	1, 950	2, 080	2, 210	2, 340	2, 470
65	1, 580	1, 710	1, 840	1, 970	2, 100	2, 230	2, 360	2, 490	2, 620	2, 750
70	1, 860	1, 990	2, 120	2, 250	2, 380	2, 510	2, 640	2, 770	2, 900	3, 030
75	2, 140	2, 270	2, 400	2, 530	2, 660	2, 790	2, 920	3, 050	3, 180	3, 310
80	2, 420	2, 550	2, 680	2, 810	2, 940	3, 070	3, 200	3, 330	3, 460	3, 590
85	2, 700	2, 830	2, 960	3, 090	3, 220	3, 350	3, 480	3, 610	3, 740	3, 870
90	2, 980	3, 110	3, 240	3, 370	3, 500	3, 630	3, 760	3, 890	4, 020	4, 150
95	3, 260	3, 390	3, 520	3, 650	3, 780	3, 910	4, 040	4, 170	4, 300	4, 430
100	3, 540	3, 670	3, 800	3, 930	4, 060	4, 190	4, 320	4, 450	4, 580	4, 710

[1] Gross volumes are inside bark and include all trees 5.0 inches d.b.h. and larger from stump to a variable top diameter not less than 4.0 inches i.b. Volumes may be converted to rough cords per acre by dividing by 80.

[2] Based on 50 1-acre plots in Carlton County, Minn. Heavy lines indicate limits of basic data. Reprinted from (*5*).

quent field checks, was within 10 percent of a ground inventory made by an independent agency.

Adjusting volumes by field checks.—When aerial volume tables are not sufficiently reliable for acceptance of pure photographic estimates and allowance must be made for defective trees, some of the plots interpreted should be mechanically selected for field measurement. For example, if 350 plots were interpreted and every 10th plot selected, 35 plots would be visited in the field. If the field volumes averaged 600 cubic feet per acre as opposed to 800 cubic feet per acre for the photo plots, the adjustment ratio would be 600÷800 or 0.75. If the 35 field plots are representative of the total, the ratio can be applied to the average photo volume per acre to determine the adjusted volume. Ratios should be computed by forest types, because hardwoods are likely to require larger adjustments than conifers.

The accuracy of aerial cruises depends not only upon the volume tables but also on the availability of recent photographs and the interpreter's ability to measure correctly. This last item may be the greatest single source of error. Each photo variable should be measured twice for an average, or two interpreters should assess each plot.

Photo estimates of pine cordwood volumes for a tract in the Georgia Piedmont[1]

County: Oconee — *Photo date:* 11-1-60
Photo No.: BQ-3BB-85, 86 — *Pine area:* 177 acres
Owner: J. Reynolds — *Scale:* 1,667 ft./inch

Pine stand[2]	Stand area	Total height	Crown diameter	Crown closure	Pine volumes per acre		Stand volume
	Acres	*Feet*	*Feet*	*Percent*	*Cubic feet*	*Cords*	*Cords*
1	18	40	10	25	380	4. 75	85. 5
2	29	30	10	5	60	. 75	21. 8
3	11	30	10	5	60	. 75	8. 3
4	18	40	15	35	610	7. 62	137. 2
5	5	30	10	15	190	2. 37	11. 8
6	11	40	15	35	610	7. 62	83. 8
7	9	30	10	65	810	10. 12	91. 1
8	17	40	15	15	260	3. 25	55. 2
9	20	50	15	15	310	3. 87	77. 4
10	27	40	15	25	430	5. 37	145. 0
11	12	30	10	15	190	2. 37	28. 4
Total pine volume (cords)							745. 5

[1] Cubic volumes derived from table 9 and divided by 80 for conversion to cords.

[2] Stands are numbered as in figure 29.

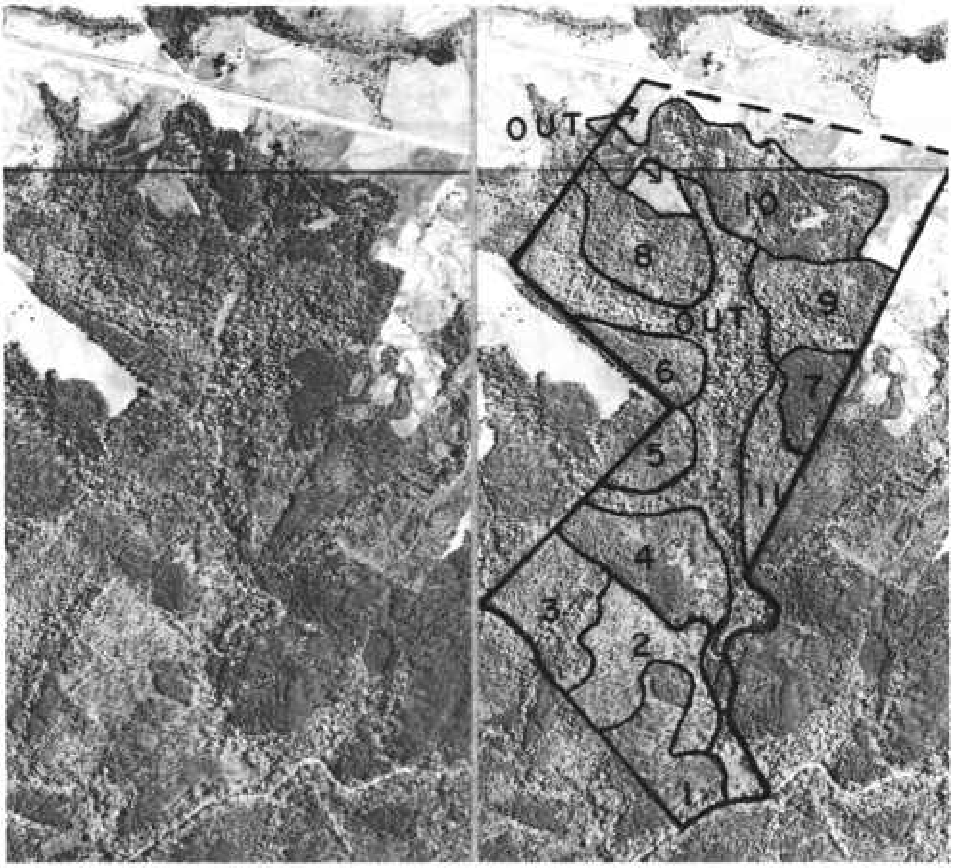

Figure 29.—**USDA panchromatic stereogram of a forest area in the Georgia Piedmont. Area and pine volume estimates were made for each of the stands numbered. Scale is about 1,667 feet per inch.**

PHOTO STRATIFICATION FOR GROUND CRUISING

A photo-controlled ground cruise combines the features of both aerial and ground estimating, offering a means of obtaining timber volumes with maximum efficiency. Photographs are used for area determination, for allocation of field samples by forest type and stand-size classes, and for designing the pattern of field work. Tree volumes, growth, cull percents, form class, and other data are obtained on the ground by conventional methods. A photo-controlled cruise may increase the efficiency, while reducing the total cost, of an inventory on tracts as small as 100 acres.

The approach to an inventory of this kind depends largely on the types of strata recognized and the method of allocating field samples. Cost and the statistical accuracy required determines the total number of field samples to be measured. Once this number has been determined, there are several ways in which the samples may be distributed among various photo classifications:

1. By area of each class. Though sometimes used, this method is often unsatisfactory because stands of low value may occupy the greatest acreage while high-value stands may be insufficiently sampled. The opposite extreme may result if value alone (volume-per-acre classes) is used.
2. By applying different cruising intensities to each class. A 20-percent cruise might be used for high-value stands, 10 percent for medium value, and 5 percent or less for low-value areas. This arbitrary method is better than using acreage alone, but it may not be the most economical and efficient.
3. By statistical methods. A preliminary cruise or a good estimate of the variability within each class must be made before the required number of plots per class can be computed. This approach is best for large tracts; for small ones it may be costly or unwieldy.

4. By a combination of area and value (volume). This is the preferred approach for small areas. A suggested procedure adopted from Johnson (*6*) and Spurr (*18*) follows.

Plot allocation by area and volume.—Assume that the tract is 1,600 acres and that 400 field plots are to be distributed among three forest types (pine, pine-hardwood, and hardwood) and three volume classes within each type (5, 8, and 12 cords per acre).

1. Stratify each forest type into volume-per-acre classes on the basis of personal experience or with aerial stand-volume tables. Precision is not required, as the volume classes are used only as a guide. Tabulate by type and acreage:

Cords per acre	*Pine (acres)*	*Pine-hardwood (acres)*	*Hardwood (acres)*
5	120	200	100
8	100	500	350
12	80	100	50
Total	300	800	500

2. Multiply the number of acres in each class by the cord volume per acre. The product is the number of cords per class:

Pine	*Pine-hardwood*	*Hardwood*
5×120= 600	5×200=1, 000	5×100= 500
8×100= 800	8×500=4, 000	8×350=2, 800
12× 80= 960	12×100=1, 200	12× 50= 600
2, 360	6, 200	3, 900

3. Add the cordage in each class to get the total for the entire area: 2,360+6,200+3,900=12,460 cords. Divide by the number of plots to get the number of cords to be represented by each plot:

$$\frac{12,460}{400}=31.15 \text{ cords per plot}$$

4. Divide the volume for each class (item 2) by the cord volume per plot to get the number of plots assigned to each class. Round to the nearest whole number. Add the plots for each class to make sure the total (400) is correct.

Pine	*Pine-hardwood*	*Hardwood*
$\frac{600}{31.15}=19.26(19)$	$\frac{1,000}{31.15}=32.10\ (32)$	$\frac{500}{31.15}=16.05(16)$
$\frac{800}{31.15}=25.68(26)$	$\frac{4,000}{31.15}=128.41(128)$	$\frac{2,800}{31.15}=89.88(90)$
$\frac{960}{31.15}=30.82(31)$	$\frac{1,200}{31.15}=38.52\ (39)$	$\frac{600}{31.15}=19.26(19)$
(76)	(199)	(125)

Total: 400 plots

Arrangement of ground samples.—If type boundaries have been accurately delineated and stands are homogeneous within the recognized classes, field plots can sometimes be taken along routes of easy travel without introducing much bias. Usually, though, it is necessary to lay out line-plot or strip cruises at right angles to topography. The cruise lines should be drawn to scale on a type map in such a way that the required number of samples within each class can be obtained. The number of plots or chains of strip that a crew can complete per day is the basis for calculating the lengths of the lines. To minimize travel, lines may be triangular or U-shaped, beginning and ending near the same starting point on a road or trail. Compass bearings and distances can be determined on the map to avoid location bias in the field. The cruise lines can then be placed on the photographs for use in the field, if desired.

Field measurements are taken by conventional procedures. Cumulative tally sheets or point-sampling may be employed to speed the tree tally. After the cordage per acre for each volume class has been determined by field sampling, the values are multiplied by the appropriate stand acreages. The result is the total volume on the tract, by forest types:

Assumed volume class (cords per acre)	*Field plots (number)*	*Field volumes per acre (cords)*	*Type area (acres)*	*Volume per class (cords)*
PINE TYPE				
5	19	3. 9	120	468. 0
8	26	8. 2	100	820. 0
12	31	11. 3	80	904. 0
Total	76		300	2, 192. 0
PINE-HARDWOOD TYPE				
5	32	5. 8	200	1, 160. 0
8	128	7. 7	500	3, 850. 0
12	39	14. 1	100	1, 410. 0
Total	199		800	6, 420. 0
HARDWOOD TYPE				
5	16	4. 7	100	470. 0
8	90	8. 6	350	3, 010. 0
12	19	13. 5	50	675. 0
Total	125		500	4, 155. 0

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Figure 1.—An aerial stereo-pair, from 9- by 9-inch contact prints. Note that the print showing the time of day is the last one in the flight line. The principal point (PP) of one photo coincides with the conjugate principal point (CPP) on the overlapping print. The flight path of the aircraft is indicated by the lines connecting the PP and CPP.