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ESTIMATING TREE HEIGHTS FROM SHADOWS ON VERTICAL AERIAL PHOTOGRAPHS

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INTRODUCTION

Aerial photographs are now being applied more and more to practical forestry--especially to forest survey. Many forest characteristics can be recognized on aerial photographs in greater detail than is possible through ground methods alone. The basic need is for tools and methods for interpreting the detail in quantitative terms.

Tree heights determined from aerial photographs can be used in estimating timber volume. Studies of white pine, northern hardwood, and spruce-fir forests--conducted in cooperation with the Harvard Forest--indicate that tree height is correlated with tree volume. The degree of correlation varies with species. (In spruce-fir forests tree height is more closely correlated with volume than it is in the northern hardwoods. Hence the use of tree heights as a measure of volume is more desirable in spruce-fir forests than in northern hardwoods.)

Shadows made by trees provide a means of measuring tree heights on aerial photographs. Seeley[1/] has developed the technical procedures for measuring tree heights from shadows on vertical aerial photographs, and has also devised a system that reduces the compilation needed to convert shadow length to tree height. Seeley's methods were first applied to forestry in this country in 1942, when the Northeastern Forest Experiment Station experimented with aerial photographs in a survey of the forests of the anthracite region of Pennsylvania.

These first attempts to determine timber volume from tree shadows showed promise. A crude volume table was constructed, based on total heights; and timber-stand volumes were estimated from tree heights and the number of trees. (The number of trees was based on a count of tree crowns.) Preliminary checks made at that time were not exhaustive, but

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1/ Seeley, H. E. Tree heights from shadows. Photogrammetric Engineering 8: 100-109, illus. 1942.

they were so encouraging that 3-1/4 million acres of forest land were surveyed with aerial photographs and the tree-shadow technique. Later these same techniques were used to interpret the forest situation on about 75 million acres of forest land in the Northeast.

During these surveys about 25 men were trained to measure tree heights from shadows. The ease with which they mastered the technique indicated that wide application of this system is possible. Present information shows that, with the shadow technique, experienced persons can estimate tree heights within 7 feet, two times out of three, at photo scales of 1:20,000. The inexperienced student can seldom attain this accuracy, but with practice he can quickly become proficient.

A later report on the Station's experience in estimating timber volume from tree heights is being considered.

MEASURING TREE SHADOWS

The stereoscope is essential for studying tree heights and land configuration on aerial photographs. Stereoscopic study provides a three-dimensional view of the land surface that is invaluable in selecting and measuring tree shadows. A direct-vision lens type stereoscope is satisfactory. The two overlapping aerial photographs and the stereoscope should be oriented by the methods explained by Rogers.[2]

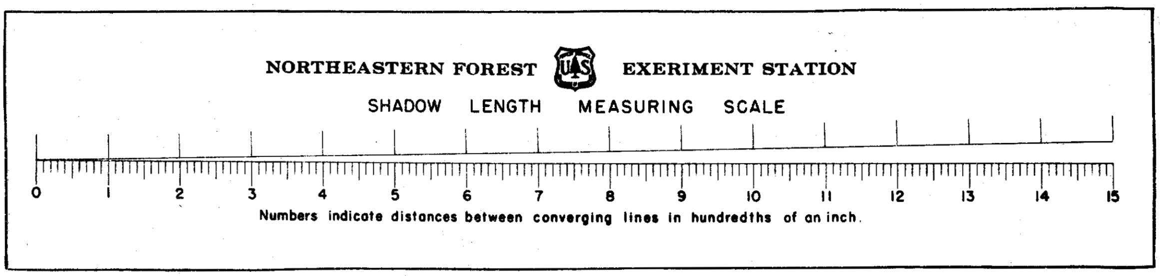

Figure 1.--Shadow wedge for measuring shadow length.

THE SHADOW WEDGE

The tree shadow may be measured with any good engineering rule. However, a greater ease of application and accuracy is obtained with a "shadow wedge" developed by Seeley. This instrument, printed on transparent celluloid, consists of two converging lines (fig. 1), with the distance between them scaled in graduations of 0.01 inch. The shadow is measured by fitting the wedge over it.

2/ Rogers, Earl J. Use of the parallax wedge in measuring tree heights on vertical aerial photographs. Northeast Forest Expt. Sta. Forest Survey Note 1. 17 pp., illus. 1946.

CAUTIONS

The measurement of shadows is subject to many sources of error. In general, the interpreter tends to underestimate because of the lack of distinct shadow from slender tree tips. Keen observation, supplemented with frequent ground checking, is needed to develop the judgment necessary for detecting errors and eliminating them. The more serious errors may be eliminated or greatly reduced if the following factors are considered.

A slope may elongate or shorten the shadow (fig. 2). Shadows on slopes should be avoided. All shadows measured should be located on flat

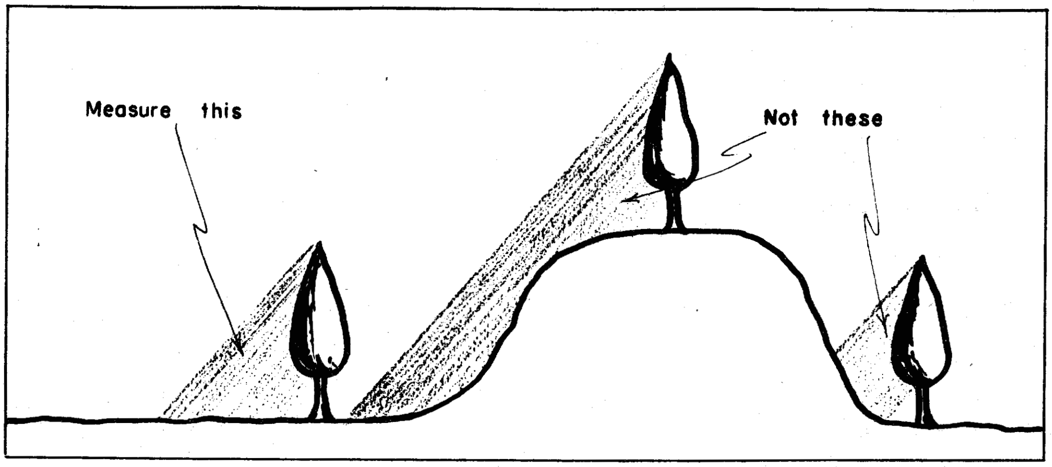

Figure 2.--Slopes are tricky.

or nearly flat land surface. Then, tree heights estimated from shadow measurements may be compared by stereoscopic study with those on slopes.

The crown canopy of the forest frequently prevents visual detection of gullies and knolls (fig 3). However, the study of the tree heights and crown sizes as compared with the stand density may indicate the presence of such configurations of the land surface. For example, we observe a group of trees with large crowns, surrounded by groups of trees with small crowns; and all the heights appear about the same. We suspect that the larger-crowned trees should be taller. But, since they do not appear any taller, it is reasonable to believe that they are in a gully. In other words, we construct the hidden configuration of the land surface through study of tree sizes. The depth of such a gully is assumed to be partially correlated with the difference in crown sizes. By a similar type of analysis, we may detect the presence of hidden knolls.

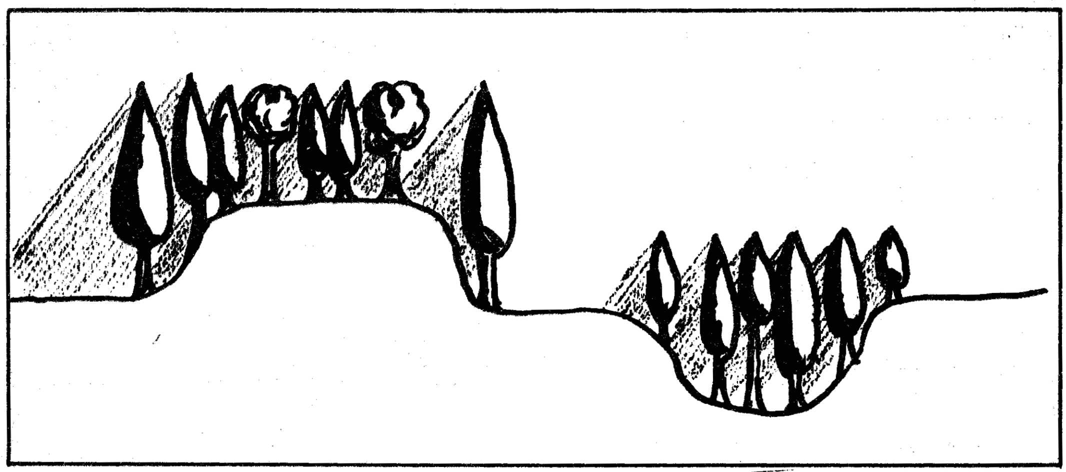

Figure 3.--Gullies and knolls are hidden.

Trees should be selected whose shadows lie on the ground (fig. 4). The height of trees whose shadows lie on underbrush or snow will be underestimated because the shadow is shortened. This is a common error in the use of shadows. Since desirable shadows are not always available, shadows in underbrush or snow may have to be measured. In this case the height of the snow depth or brush depth is estimated and added to the tree height obtained from the shadow.

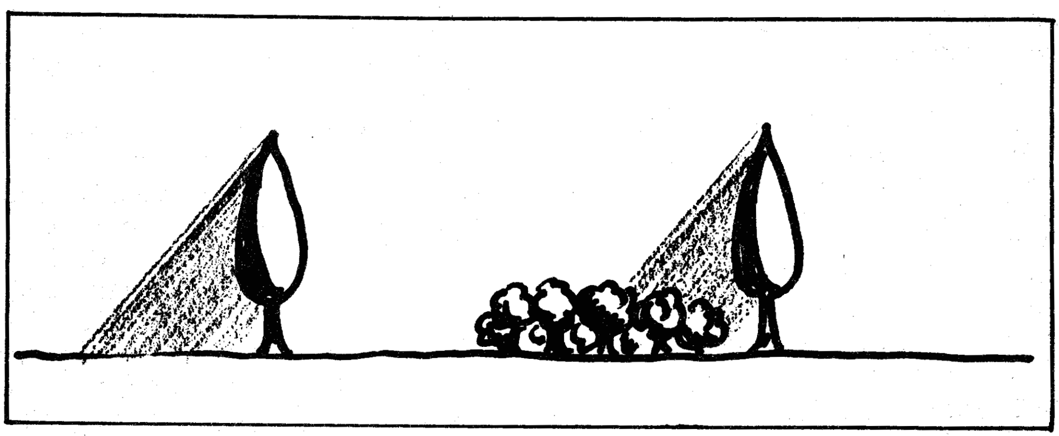

Figure 4.--Underbrush shortens shadows.

Frequently clear shadows cannot be found because of interference from other trees (fig. 5); thus, the shadows are not completely visible. This error is aggravated when the sun is low in the sky, producing extremely long shadows.

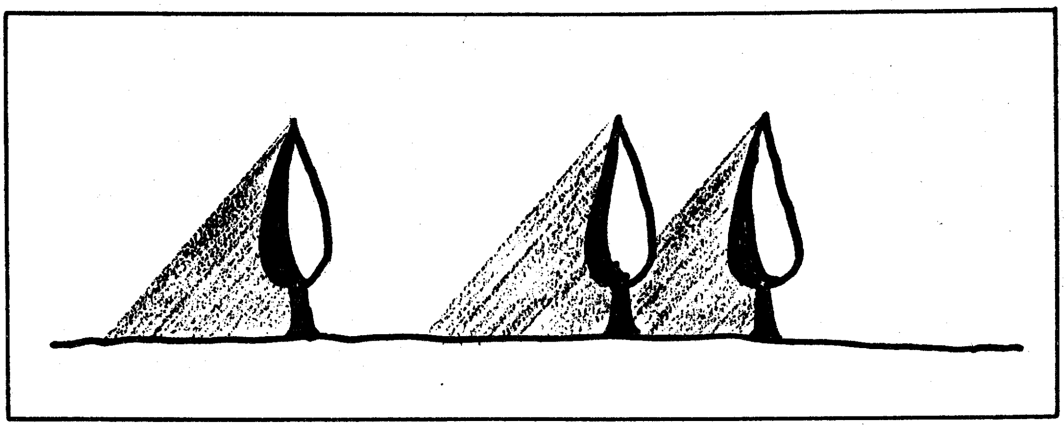

Figure 5.--Interference shortens shadows.

Large crowned open-grown trees tend to have long shadows (fig. 6). These errors are common in open old-growth forest. The shadow tip is produced by a side branch and not by the top of the tree, thus producing a long shadow.

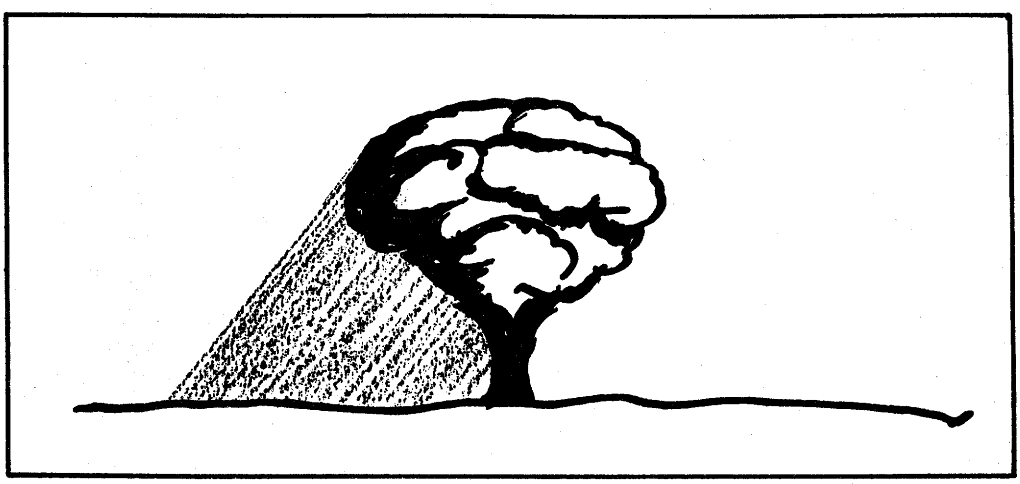

Figure 6.--Large crowns lengthen shadows.

Leaning trees are not a serious source of error because most trees are comparatively straight (fig. 7). Shadows of trees leaning toward the sun are generally shortened, and height is apt to be underestimated. Shadows of trees leaning away from the sun tend to be lengthened slightly.

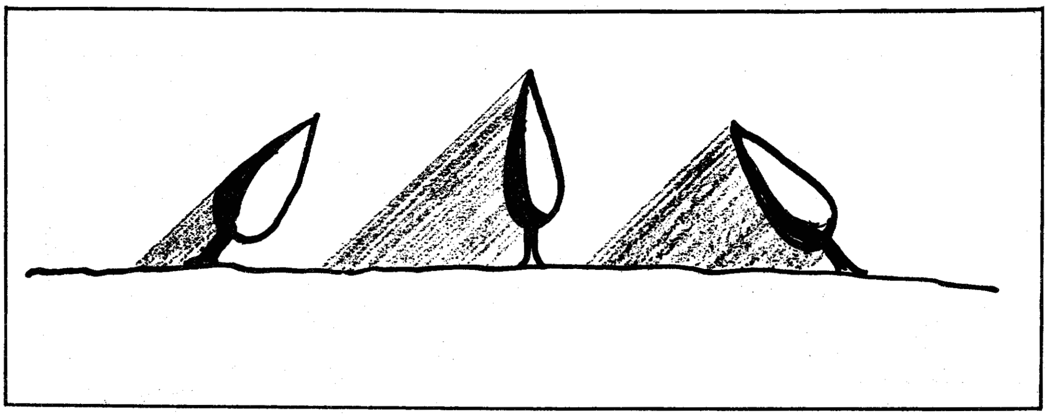

Figure 7.—Leaning trees cast shadows longer or shorter than those of straight trees.

Care is needed in studying tree shadows near the edges of aerial photos. An aerial photo does not show a tree image in a true vertical projection except near the center of the photo, and the taller the tree, the greater the displacement.

A tree's shadow is measured from the base of the tree to the tree tip. Since the base is not visible on aerial photos, the location of the tree base is figured to be near the center of the crown. This causes serious errors in measuring shadows of trees near the edges of the photo. When the tree image is displaced toward the shadow (fig. 8, A, B, C) there is a tendency to underestimate. When the image is displaced away from the shadow (fig. 8, G, H, J) there is a tendency to overestimate.

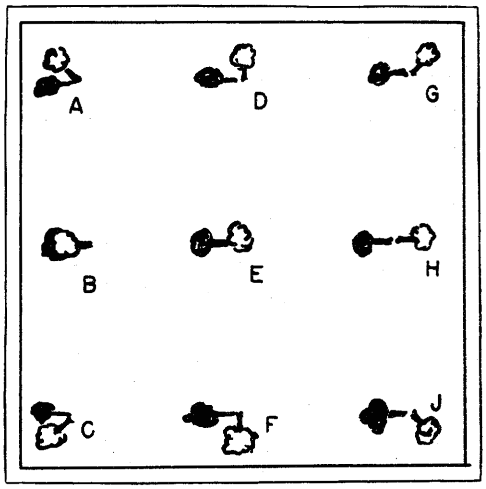

Figure 8.—Images near edges of the photo are displaced.

CONVERTING SHADOW LENGTH TO TREE HEIGHT

Shadow length can be converted to tree height readily through the use of graphs3/ (fig. 9). Such graphs may be prepared for any area and are necessary only for each two degrees of latitude.4/ Only four items are required: the geographic location of the area, the time of day photographs were made, the date, and the photo scale. The following steps outline the use of the graph.

1. Locate nearest longitude and latitude of the area photographed. This can be determined from local maps.

2. Select the graph corresponding to the nearest latitude. Graphs are constructed for each two degrees of latitude.

3. Estimate the apparent solar time. On longitudes 75°, 90°, 105°, and 120° the apparent solar time is the same as the standard time.

3/ The graphical solution of the astronomic triangle to obtain tree heights is based upon several assumptions:

1. That the declination of the sun for a given time is the same for all years.

2. That the declination of the sun for a given time in the spring months (January-May) and the corresponding fall months (July-November) is the same.

3. That the declination of the sun at noon of any given day is the same through that day.

4. That the equation of time corrections are the same for all years.

5. That computations for a given latitude are the same for plus or minus 1 degree of that latitude.

6. That computations for a given time longitude, 75°, 90°, 105°, etc., are the same for all time longitudes.

7. That interpolations for dates other than the 21st day at noon of each month are proportional to the lapse of time between the days of computations.

4/ Graphs similar to figure 9 have been prepared for all even-numbered latitudes from 36° North to 48° North. Computations are completed for the even-numbered latitudes from 22° North to 34° North. These graphs and computations are available upon request.

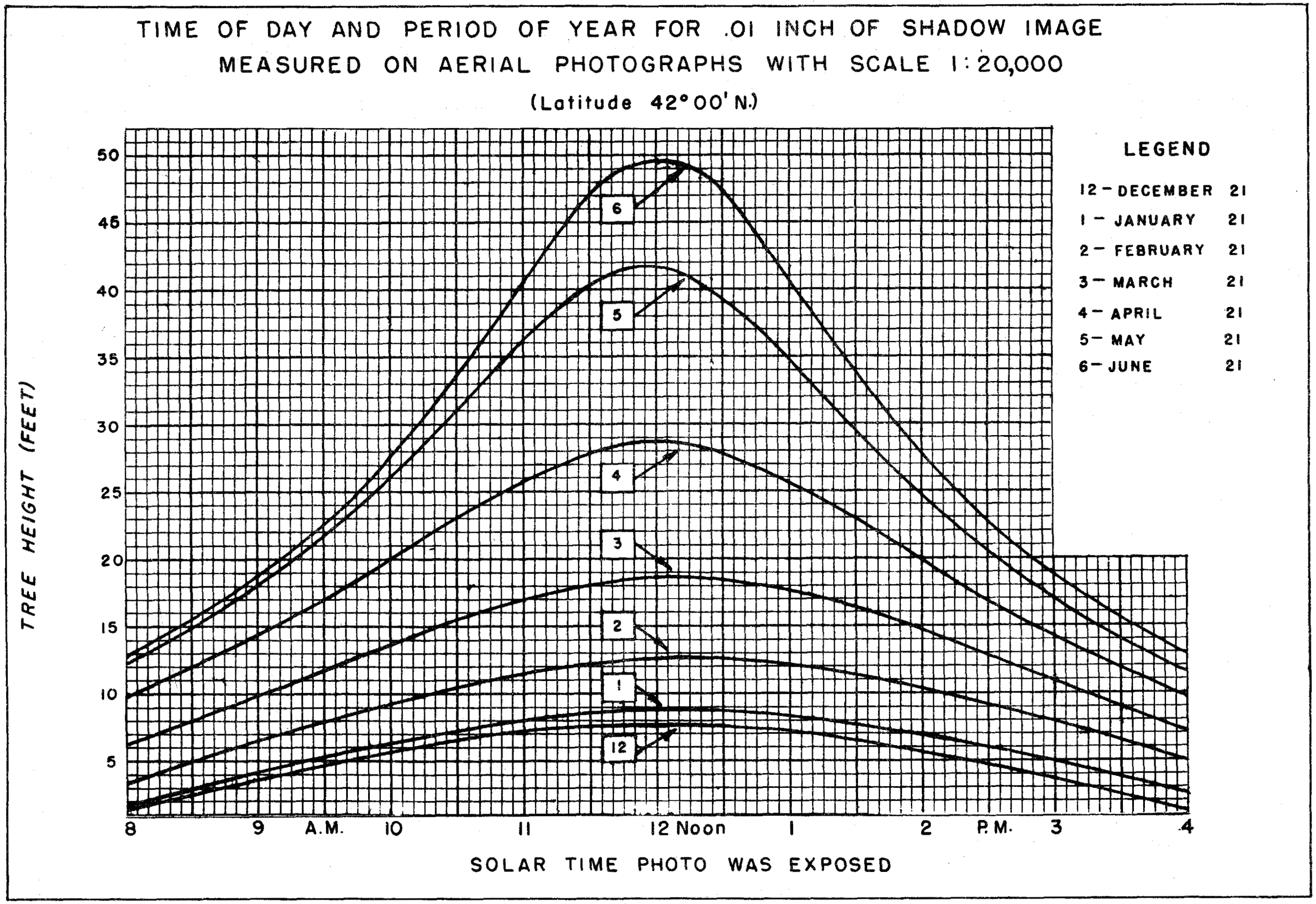

Figure 9.—Type of graph used to convert tree shadows to tree heights Graph is for two degrees of latitude (41-43) and all longitudes. This graph is for photos taken from December 21 to June 21.

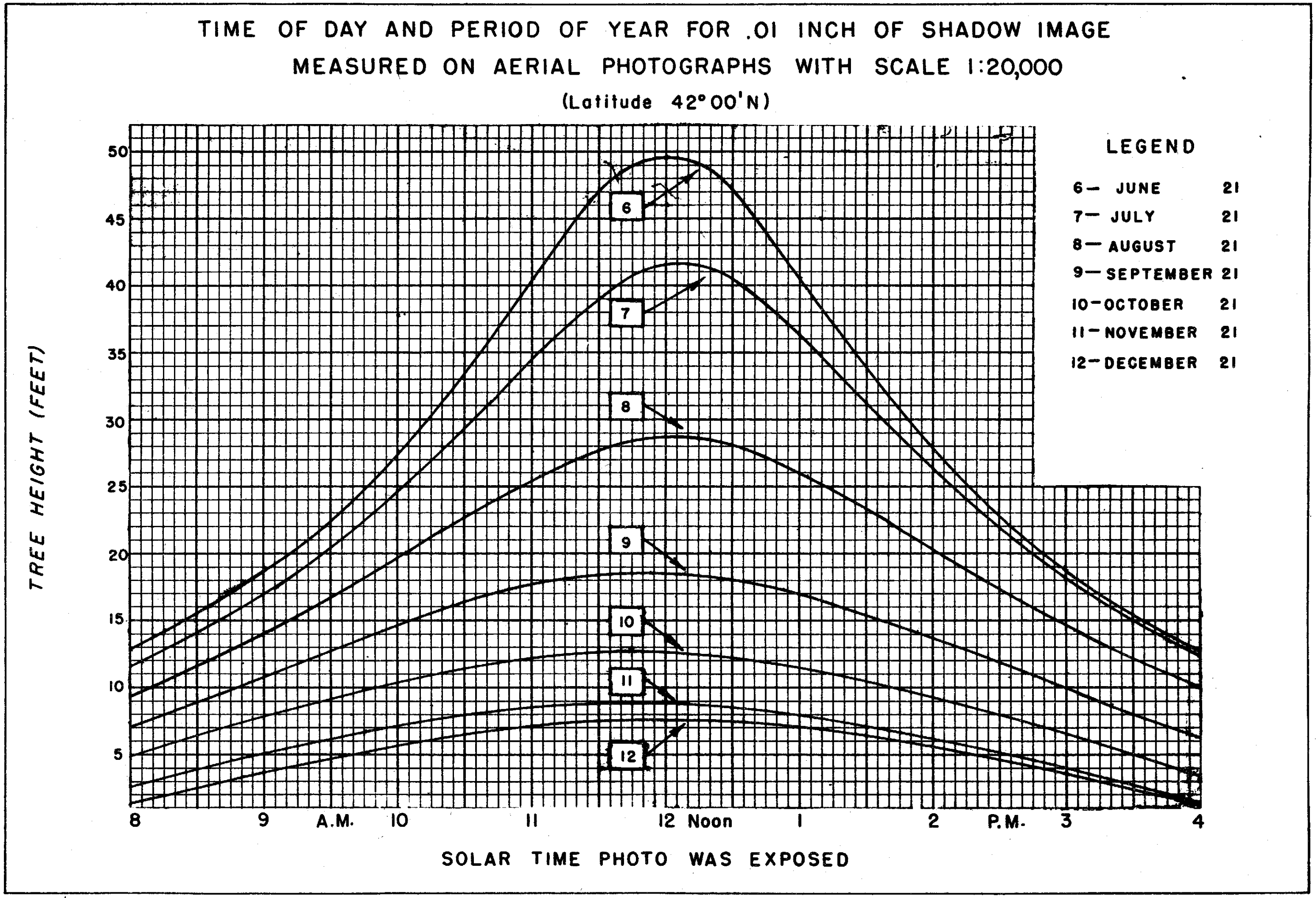

Figure 10.—Graph for photos taken from June 21 to January 21.

For geographic areas either side of these longitudes, add 4 minutes to standard time for each degree of longitude to the east and subtract 4 minutes for each degree of longitude to the west.

4. On the graph select the coordinate corresponding to apparent solar time and read up to the date photo was made, interpolating where necessary. At this intersection, read over to the scale on the left and find the tree height. This is the tree height in feet for each 0.01 of an inch of tree shadow measured on a photo whose scale is 1:20,000.

5. For other photo scales, the tree height in feet for 0.01 of an inch of shadow is directly proportional to the change of scale.

Example

Given an aerial photo exposed at 3:30 p.m., EST, Sept. 10, 1942. Scale 1:10,000; latitude 42° N, longitude 80°.

What is the conversion factor--tree height in feet for each 0.01 inch of shadow?

Solution:

Standard time - 3:30 p.m.

Subtract 4 minutes for each degree west of longitude 75° -20

Solar time - 3:10 p.m.

Select the 42° N latitude graph (fig. 10). From this, tree height for 0.01 inch of shadow at 3:10 p.m. on Sept. 10 is - - - - - - - - - - - - - 10.5 feet

Correct for scale difference $\frac{10,000}{20,000}$ x 0.5

Tree height for each 0.01 inch of shadow measured on aerial photo - - - - - - - - - - - - - - 5.25 feet

TIME OF PHOTO EXPOSURE

The time of photo exposure is recorded on the contact print of the first and last photos in any flight. If, however, time records are lacking or inadequate, a graphical solution of the sun-dial formula (fig. 11) can be used to estimate the apparent solar time of photo exposure.5/ The following steps are necessary:

1. With the aid of local maps, orient the photo and draw a true north-south line on it.

2. Also, draw a line parallel to the shadows on the photo so that this line will intersect the north-south line.

3. Measure the angle of intersection clockwise from north to the nearest degree. This angle is the azimuth of the sun's position from north.

4. From the graph (fig. 11) select the coordinate corresponding to this azimuth. Read to the right to the date the photo was made, interpolating where necessary. Read down to find the time the photograph was made.

5. This time is the standard time for the time longitudes, 75°, 90°, etc., and the apparent solar time for other longitudes. Therefore, the time determined from Figure 11 corresponds to apparent solar time used in Figure 9.

The same assumptions are made for calculations in Figure 11 as were made for the calculations in Figures 9 and 10.

5/ Fig. 11 has been prepared only for latitude 41°30'.

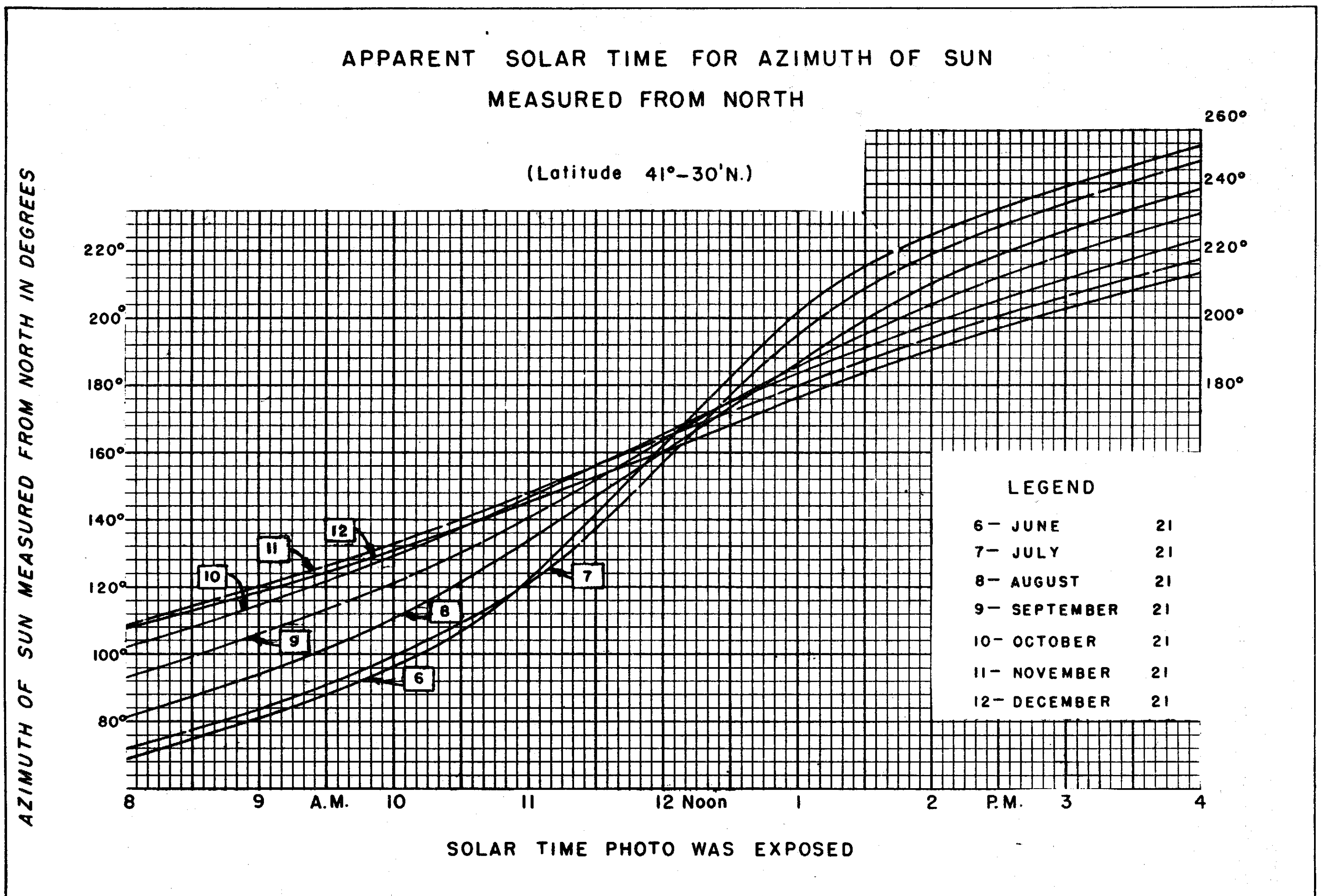

Figure 11.--Type of graph used to estimate time photo was exposed. Graph is for period December 21 to June 21, for six degrees of latitude (38°30'-44°30'), and all longitudes.

AID TO DATE INTERPOLATION ON GRAPHS

The interpolation of the date on the two graphs may be facilitated by the use of a special device (fig. 12). This device can be reproduced on glass plates or celluloid.

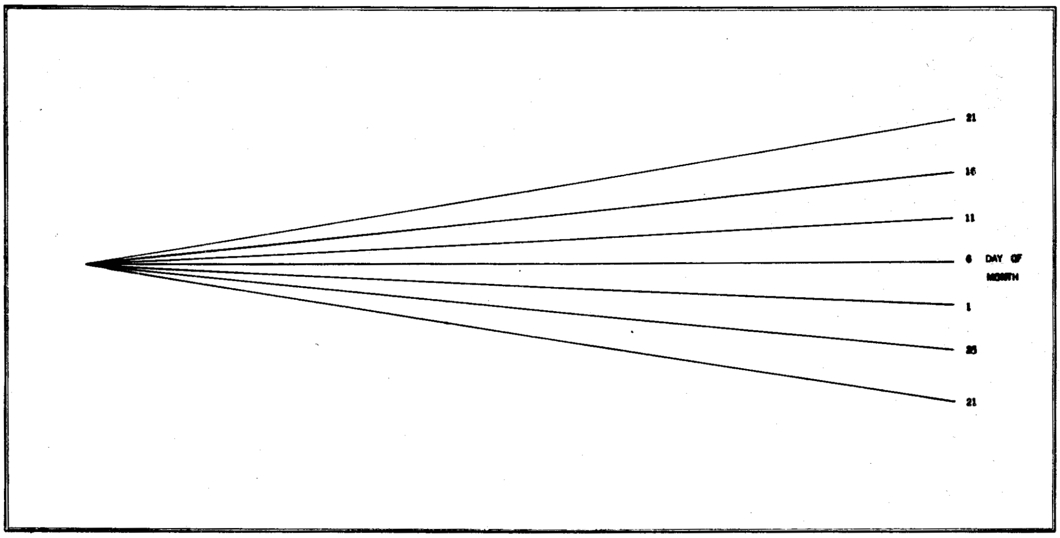

Figure 12.--Wedge for interpolating date.

It is used as follows:

1. On the desired time coordinate, locate points on each of the two curves between which the date falls.

2. Place the outside lines of the device (marked "21") over these two points. The outside lines should coincide with the curves at the points located.

3. Interpolate the date corresponding to the date photos were made Read the tree height at that point.

SCALE OF VERTICAL AERIAL PHOTOGRAPH

A vertical aerial photograph seldom has a constant scale. Its scale will vary with two factors: the amount of camera tilt from vertical and the amount of ground relief photographed. Present techniques of taking aerial photographs maintain a near-vertical position of the camera, which will cause only slight changes of scale. Therefore, it is thought that this effect on scale is not sufficiently serious to discuss here. But, changes in ground relief are serious and require further elaboration on their effect on scale.

An approximate photo scale is indicated on the photos or on the photo index mosaics. By the use of this scale tree heights within 10 feet, two times out of three, may be estimated for photo scales of about 1:20,000. To improve the scale control, the following methods are suggested:

For Flat Terrain

If the ground is flat or nearly so, the scale of a photo may be determined from one line.

$$\text{R.F., representative fraction} = \frac{\text{Photo distance}}{\text{Ground distance}} = \frac{g_1 g_2}{G_1 G_2} = \frac{d}{D}$$

Thus, if the distance between two points along a line on the photo is 6.3 inches and the scaled ground distance from a map between the same two points is 10,800 feet, then the

$$\text{R.F.} = \frac{6.3}{10{,}800 \times 12} = \frac{1}{20{,}570} \text{ or } 1{:}20{,}570$$

This scheme may be used for forest survey of large areas in flat terrain. The average scale for a photo project should be calculated from about 10 control lines scattered at random.

For Rough Terrain

If ground surface is rugged, the photo scale will vary with change of elevation. For such photos, the scale is calculated from one line and the ground elevation at each end of the line.

1. Calculate the approximate flying height:[6]

$$(H) = \frac{Df}{d} + \frac{h_{G_1} + h_{G_2}}{2} \quad \text{where,}$$

(H) = Approximate flying height above sea level, in feet

D = Ground distance between ground points G_1 and G_2, in feet

d = Photo distance between points G_1 and G_2, in inches

f = Focal length of camera lens, in inches

h_{G_1} = Elevation of point G_1 above sea level, in feet

h_{G_2} = Elevation of point G_2 above sea level, in feet

2. Then, using flying height, photo scale at the point of interest (G_3) is calculated:

$$R.F. = \frac{f}{(H) - h_{g_3}} \quad \text{where,}$$

(H) = Approximate flying height above sea level, in feet

h_{G_3} = Elevation of the ground above sea level at point of interest obtained from topographic map, in feet

f = Focal length of camera lens, in feet.

6/ Church, Earl F. Elements of photogrammetry. 95 pp., illus. Syracuse, N. Y. 1944.