the beam of light to each $x$, $y$ position in turn and converting the adopted gray scale value $I$ to an appropriate light intensity for each element of the orthophoto. With photographic film exposed in this manner and then developed, the result is a contoured orthophotograph ready for the final manual completion steps.

Quadrangle edge joining can be accomplished by including adjacent photographic data in the current quadrangle's correlation and aerotriangulation adjustment. This data consists of the photographic scan quantities as well as $[M]$ and $\bar{R}$ values. (The positions and attitudes of the joining photography are held fixed.) A manual alternative to this edge-joining solution would be to correct the edge of a quadrangle by the method described for incorporating field corrections.

As previously stated, it will be impractical to store the immense amount of data contained in the photographs on magnetic tape. The number of tapes required and the inability to store the data in matrix array preclude this form of storage. Instead, the photographic plates themselves should form an addressable (in $x$, $y$ position) memory. The computing device used in the correlation step should then be capable of extracting the same information directly from the photographs, as shown in tape 6, Figure 2.

The system depicted in Figure 2 is envisaged as performing all correlation required in triple-coverage areas (down the flight line) and in side-lap areas. The final position of each point where correlation is found is a function of all the object rays that pertain to that point: not just the two from a specific model. This facility raises the possibility of strengthening the adjustment by increasing the side lap to 60 per cent, thus making use of photogrammetric data in a manner that has been impracticable heretofore.

### References


1. Articles covering the Direct Geodetic Restraint Method:

   "Analytical Aerotriangulation by the Direct Geodetic Restraint Method," PHOTOGRAMMETRIC ENGINEERING, September 1959, H. F. Dodge.

   "A Geometrical Foundation for Aerotriangulation," *Progress Report 3—Analytical Aerotriangulation Research*, Topographic Division, U. S. Geological Survey, December 1959, H. F. Dodge, D. S. Handwerker, and R. C. Eller.

2. Articles on Schmid-Brown Method:

   "An Analytical Treatment of the Orientation of a Photogrammetric Camera," PHOTOGRAMMETRIC ENGINEERING, December 1954, Dr. H. Schmid.

   "An Analytical Treatment of the Problem of Triangulation by Stereophotogrammetry," *Ballistic Research Laboratory Report 961*, October 1955, Dr. H. Schmid.

   "A Treatment of Analytical Photogrammetry with Emphasis on Ballistic Camera Applications," *RCA Data Reduction Technical Report No. 39*, August 1957, D. C. Brown.


# *A Test of Stand Age Estimation from Aerial Photos in Even-Age Douglas-Fir*


DAVID A. BERNSTEIN,[1]
*U. S. Forest Service,*
*Portland, Oregon*


(*Abstract is on the next page*)

## Introduction

AGE-CLASS distribution is one of the important items collected in the inventory of a forest management unit where even-age management is practiced. However, even though inventory plots give volume in each age class, they do not tell *where*. This *where* must be known if satisfactory action plans

[1] The author is with the Division of Timber Management, Pacific Northwest Region, U. S. Forest Service, Portland, Ore. This study is an outgrowth of the aerial survey techniques research program conducted under the supervision of the Pacific Northwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Portland, Ore.

are to be made. A stand-age-class map fulfills this need.

The usual way to map age classes is to delineate on aerial photos what appears to be an even-aged stand and then determine its age on the ground with several random increment borings of trees within the stand. In most accessible stands, ground sampling for age can be performed for a reasonable cost. However, ground sampling becomes expensive in stands that require much foot travel to reach. Therefore, aerial photo determination of stand age was tested for use in inaccessible stands.

ABSTRACT: *Stand age is one of the information items needed for forest management planning in even-aged Douglas-fir. The possibilities of obtaining stand age from aerial photos were explored. A formula for determining stand age, using photo-measured tree heights and crown closure, was developed. In a test of the formula on 20 even-aged stands, only 7 were correctly placed in their proper 20-year age class. On the basis of this test, it was concluded that using aerial photos to determine stand age was impractical.*

The possibilities of aerial photo stand age determination were explored by Willingham (1957) in northeastern Florida. He found that correlation coefficients between stand age and the photo-measurable variables of tree height, crown diameter, crown closure, and number of trees were all highly significant. A formula for the linear estimate of age was derived which would predict stand age within $\pm 2.5$ years at the 5 per cent level with 12 observations, using height and crown closure as variables. These positive results encouraged a test of stand age estimation from aerial photographs in the Douglas-fir type.

## BASIC DATA

The basic data for this test came from 282 plots of even-aged Douglas-fir stands in western Oregon and southwestern Washington. These plots were marked on recent 1:12,000-scale panchromatic photos. The ages of 211 of these plots were judged by photo interpretation to be 160 years and under and were used in the test. Crown closure and average crown diameter for each plot were estimated on the photos by two experienced interpreters. Average heights of the dominant and codominant trees and stand age were determined in the field. This procedure is also used in the construction of aerial photo volume tables. Studies have shown that photo measurements are subject to a bias that varies with individual interpreters. Therefore, any volume table or age-prediction formula based on photo-measured heights would be valid only for the person who supplied the data used in the table and formula. Interpreters can adjust their own height measurements to a field basis but cannot adjust to some other interpreter's unknown photo measurement (Pope, 1962).

Stand heights ranged from 50 to 235 feet and averaged 123 feet. Stand ages ranged from 30 to 200 years and averaged 80 years. Three plots where stand age exceeded the 160-year age limit were included in the data because photo interpretation placed them in a younger age class.

## ANALYSIS

Stand height, crown closure, and crown diameter were independent variables selected by preliminary testing as being the photo-measurable characteristics most closely related to age. Multiple regression analysis, employing an electronic computer program, was used to determine the equation that best related the various independent variables to stand age (Grosenbaugh, 1958). Actually, these variables were expressed in a number of different ways so nine variables were used in the machine program. They were: height in feet $H$, per cent of crown closure $C$, crown diameter in feet $D$, height squared $H^2$, crown closure squared $C^2$, height times crown closure $HC$, height squared times crown closure $H^2C$, height times crown closure squared $HC^2$, and height squared times crown closure squared $H^2C^2$.

## RESULTS

The "formula of best fit" (Grosenbaugh, 1958) contained four variables: height, crown closure, height squared, and crown closure squared.

The formula is as follows:

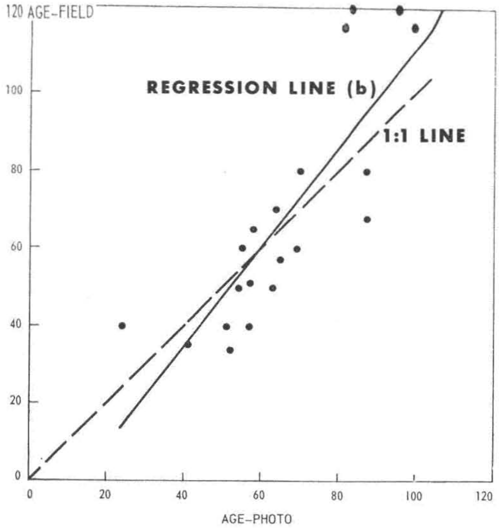


FIG. 1. Diagram of differences between photo-determined and field-determined ages for 20 even-aged Douglas-fir stands.

$$Y = -57.97 + 1.0924H + 1.6178C - 0.0024H^2 - 0.0132C^2$$

where

$Y$ = stand age
$H$ = field-measured stand height
$C$ = crown closure.

The multiple correlation coefficient is 0.613, which is highly significant. The standard error of the estimate for stand age of a single plot is $\pm 29$ years for stands averaging 79 years.

High correlation coefficients would be useful in double sampling if the objective was to determine the average age of all the stands in an area. However, this type of information is never required. What is needed is an in-place age estimate for each stand. The standard error of the estimate gives some indication of what might be expected in age determination success. But to base age determination on a single observation in a stand would be unrealistic. In practical application, a better estimate of age would be averaged from a series of plots over a large area. On the other hand, photo estimates of stand height, the most important factor in age determination, generally vary somewhat from field-measured stand heights. This variation tends to weaken age estimates. The effect of these various considerations on results when actually applying the age determination formula to photo-measured stands is unknown. Therefore, an aerial photo stand age estimation test was made on 20 even-age Douglas-fir stands in the Cascade Mountains of Oregon and Washington.

The 20 stands ranged in size from a few to several hundred acres and occupied a variety of sites. Stand ages ranged from 35 to 130 years. Stand age was determined from several increment borings of trees in each stand. The photo measurements consisted of several parallax bar height readings scattered throughout the stand along with a series of $\frac{1}{5}$-acre crown closure readings covering the whole area.

Figure 1 shows in diagram form the differences between photo-determined age and

TABLE 1

VARIATIONS AND MULTIPLE CORRELATION COEFFICIENTS FOR SEVERAL COMBINATIONS OF PHOTO-MEASURABLE VARIABLES

| *Variables* | *Variation Accounted for* | *Multiple Correlation Coefficient* |
|---|---|---|
| | *Per Cent* | |
| Formula 1 (height, crown closure, and crown diameter)—nine: $H, C, D, H^2, C^2, HC, H^2C, HC^2, H^2C^2$ | 39.3 | 0.627 |
| Formula 2 (height and crown closure)—eight: $H, C, H^2, C^2, HC, H^2C, HC^2, H^2C^2$ | 38.8 | 0.623 |
| Formula 3 (height and crown closure)—statistically best four: $H, C, H^2, C^2$ | 37.6 | 0.613 |
| Formula 4 (height only)—two: $H, H^2$ | 35.2 | 0.593 |
| Formula 5 (crown closure only)—two: $C, C^2$ | 9.6 | 0.311 |
| Formula 6 (crown diameter only)—one: $D$ | 16.3 | 0.404 |

field-determined age on these 20 stands. Any photo-determined age that coincided with field age would lie directly on the 1:1 line. The regression line (b) is for the 20 observations. Field and photo ages are obviously correlated, and since the line of relationship does not differ significantly from the 1:1 line, it would appear that the formula could be used with some degree of confidence. The standard deviation of the difference between field and photo ages is ±17 years.

Another way of evaluating these results is to consider how many of these 20 stands could be correctly assigned to their proper age group. The 20-year age groupings suggested for National Forests (Gross, 1950) were used. It was found that only 7 of the 20 stands were placed in their correct age group. These latter results present a weak case for aerial photo age determination.

This study showed that using aerial photos to determine a usable stand age was impractical. However, for the benefit of others who may wish to study this problem further, the findings on the correlations between stand age, stand height, crown closure, and crown diameter are presented.

The formulas developed showed several interesting relationships between photo-measured variables and stand age. Table 1 shows the amount of variation accounted for by the various formulas.

In this test, there was very little loss when one variable, crown diameter (formula 2), was dropped. There was only a slight drop in variation between the nine variables of formula 1 and four variables of formula 3. Most important was the finding that height measurements alone (formula 4) can achieve most of the possible aerial photo age determination.

## References

Grosenbaugh, L. R., 1958, "The Elusive Formula of Best Fit: A Comprehensive New Machine Program," U. S. Forest Serv. South. Forest Expt. Sta. Occas. Paper 158, 9 pp., illus.

Gross, L. S., 1950, "Timber Management Plans on the National Forests," U. S. Dept. Agr., Washington, D. C., 59 pp.

Pope, Robert B., 1962, "Constructing Aerial Photo Volume Tables," U. S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 49, 25 pp., illus.

Willingham, S. W., 1957, "Estimation of Forest Inventory Data from Aerial Photo Measurements," *Forest Science*, Vol. 3, pp. 270–274.

# *A Report on the Camera Calibration Phase of the C&GS Satellite Geodesy Program**

EUGENE A. TAYLOR,
*Lt. Cmdr.*,

B. FRANK LAMPTON,
*Cartographer*,
*U. S. Coast & Geodetic Survey*

(*Abstract is on next page*)

## Introduction

The Coast and Geodetic Survey is developing a satellite geodesy program based on the photogrammetric tracking of passive satellites, such as Echo I, simultaneously from three or more mobile camera stations. In this approach, the satellite becomes a temporary elevated target visible from each tracking camera; thus the three-dimensional configuration will form a geometric model free from orbital uncertainties associated with the dynamic approach. Scale will be provided to the models by measuring precise baselines several hundred miles in length and accurate to 1 part per million. Data reduction techniques are based on those developed by Dr. Hellmut Schmid, formerly with the Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, and presently with GIMRADA, Fort Belvoir, Virginia.[1]

It is planned to extend a network of satel-

[1] Now scientific advisor to the Coast and Geodetic Survey.

* Presented at the 1963 Annual Meeting of the American Society of Photogrammetry in Washington.