A STUDY OF POSSIBLE USES OF CONTINUOUS STRIP AERIAL PHOTOGRAPHY IN FORESTRY

May, 1949 Arnold L. Mignery

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by

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A STUDY OF POSSIBLE USES OF CONTINUOUS STRIP AERIAL PHOTOGRAPHY IN FORESTRY[1]

INTRODUCTION

Foresters learning of the spectacular war-time achievements of continuous strip aerial photography immediately speculated on its possible application to their own profession. This new aerial photographic technique had given water depth measurements along landing beaches to within nine inches. In another instance the large scale photographs from the Sonne camera, as it is usually called, revealed an enemy command post when communications wire was seen leading into its carefully camouflaged position. The Sonne camera permitted fast, low-flying military aircraft to make photographs of remarkable detail and clarity on a scale as large as 1/300.

A very successful application of continuous strip

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[1] The writer wishes to thank the U.S.Naval Air Training Center of Pensacola, Florida and the personnel of the Brewton Branch of the Southern Forest Experiment Station for their cooperation in supplying the photograph and field data used in this study. The Chicago Aerial Survey company generously provided a continuous strip stereoscopic viewer for the study. Much valuable information was supplied by the following authorities on continuous strip photography: Professor Robert N. Colwell, Colonel George W. Goddard, Mr. E.W.Fuller, Mr.Phillip S.Kistler, and Commander V. Van Keuren. The writer is grateful to Professor John Carow and Dr. Samuel A. Graham of the School of Forestry and Conservation, University of Michigan, for their valuable criticism and encouragement throughout the period of this study.

photography to wildlife census work was made in late 1948 when the Air Force cooperated with the U. S. Fish and Wildlife Service in photographing ducks on marshlands of the San Joaquin Valley. A jet fighter plane flying at more than 400 miles per hour photographed ducks before the engine noise, which trails the plane at this speed, could frighten them.[1]

The possibility of photographic measurements approaching the accuracy of data from field work was suggested by these dramatic achievements of the Sonne camera. An opportunity to investigate some of the forestry applications of this new type of photography presented itself when a stereoscopic continuous strip photograph was made available to the writer through the courtesy of the U. S. Navy and the Southern Forest Experiment Station.

It is the purpose of this report to give the results of an investigation of the forestry applications of this continuous strip photograph of the upland longleaf pine type of southern Alabama. The basic principles of the Sonne camera are briefly described together with the equipment needed to view the photograph and to make various measurements. The facts collected show that present Sonne equipment has an extremely limited usefulness in forestry. Finally, information is presented which indi-

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[1] From a United Press dispatch of December 24,1948 in the Mobile, Alabama Press-Register.

cates that the continuous strip camera may be modified to provide a useful supplement to conventional aerial photographs.

SUMMARY

The Sonne camera is an adaptation of the old panoramic or circuit camera. The conventional shutter is replaced by a focal plane slit which, with the lens, remains open during photography. The film moves past the slit at a speed proportional to the ground motion of the airplane. Thus at the moment of exposure there is no relative motion between the projected image of an object and the film passing the slit. The resulting photograph is a continuous ribbon picture of the area along the plane's line of flight. Stereoscopic pictures are obtained by partitioning the camera cone in two and providing a lens for each half. One lens photographs ahead of the plane and the other to the rear. The two strips so produced are photographed on the same film base; this provides a continuous stereoscopic pair from which parallax difference measurements are made.

It was found that the present short focal length Sonne cameras have serious limitations so far as forestry is concerned. The chief defects are blurring that results from the differential movement of the upper and lower parts of tall objects and the great scale variation that is introducted by very slight changes in the distance between the camera and the ground.

Sonne photographs have certain advantages over conventional photographs for species identification, par-

ticularly with color film. Probably the best use of present cameras would be for the evaluation of understocked areas, studies of young plantations, and other enumeration work.

The measurements of height and diameter showed wide variations from the actual field data. Since narrow area coverage restricts the Sonne camera to a sampling technique, the data obtained are considered too erratic to justify the use of present equipment for mensuration.

There are indications that Sonne type cameras with longer focal lengths would solve some of the present difficulties. When suitably adapted, it is probable that continuous strip photography will be a useful supplement to the standard type aerial photographs now so advantageously used in forestry.

REVIEW OF LITERATURE

The Sonne continuous strip camera was developed and built during World War II by the Chicago Aerial Survey Company for the U. S. Navy and the Army Air Corps in co-operation with research personnel of both services. War-time secrecy prevented the general publication of any information regarding the Sonne camera until 1946 when two magazine articles appeared. One of these reports entitled "How Deep is the Ocean?" (Snyder and Frame, 1946) gave a popular account of the spectacular results achieved with the Sonne camera on landing beach reconnaissance in the Pacific area. The other articles was a technical report by Kistler covering the theory and photogrammetry of the continuous strip camera.

No other full articles relating to the continuous strip camera were published until July 1948 when Katz reported recent experimental attempts to apply the Sonne principle of image motion compensation to aerial cameras with conventional shutters. He also told of a new technique in using the Sonne camera for oblique photographs of excellent quality.

The December, 1948 issue of Photogrammetric Engineering contained a symposium on military photographic interpretation that presented more details on the use of continuous strip photography for water depth determinations and the interpretation of vegetation.

In his text, *Aerial Photographs in Forestry* (1948), Spurr describes the Sonne camera and mentions several possible applications of continuous strip photography to forestry. Kistler (1946) also states that there are possible applications to forestry. No reports were found of instances where data from Sonne photographs had been compared with field measurements of sample forest areas.

Correspondence was used to supplement the meager amount of published material. Valuable information was received from the following: P. S. Kistler who aided in the development of the U. S. Navy Sonne camera and later superintended its use in the Pacific combat area; R.N.Colwell, assistant professor of forestry at the University of California, who worked with the Sonne camera while in the U. S. Navy; Commander Van Keuren of the U. S. Naval Photographic Interpretation Center; Colonel George W. Goddard of the U. S. Air Forces who pioneered in developing the model S-7 Sonne camera used in the European theater of operation; E. W. Fuller, president of the Chicago Aerial Survey Company, the only organization now doing commercial work in continuous strip photography; the Eastman Kodak Company who supplied comparative cost data for film.

Copies of the letters received are to be found in the Appendix I of this report beginning on page 41.

DESCRIPTION OF THE SONNE CAMERA

The continuous strip, or Sonne, camera is simply an adaptation of the old circuit or panoramic camera to aerial work. The original model of the continuous strip aerial camera was developed about 1936 by Fred Sonne of Chicago while working on aerial survey problems (Snyder and Frame, 1946). The initial camera made no provision for stereoscopic viewing and did not meet military requirements.

By 1940 the U. S. Air Forces had brought the Sonne camera to a high state of development. Later work by both the Army and the Navy in conjunction with the Chicago Aerial Survey Company resulted in a double lens camera which permitted stereoscopic viewing of paired photo strips which appear side by side on the same film base (See figure 1, page 67). Actual combat use of the Sonne camera did not come until 1944 when the Army used its model S-7 in the Normandy invastion. The Navy made effective use of continuous strip cameras in the Okinawa campaign (Kistler, 1946). Photographs were used mainly to determine water depths along landing beaches; but, in addition, on Okinawa the pictures revealed mine fields and cave defenses. The Sonne camera was an American development; none of the Axis nations had a camera to compare with it.

The principle of the strip camera operation is quite different from that of conventional aerial cameras. The film moves continuously past a fixed focal plane slit that is constandly open during the period of photography. The slit, although located in the focal plane, is not a focal plane shutter. The film, which moves backward (Lundahl, 1948) with respect to the plane's forward motion, is synchronized in speed according to the following relationship (Kistler, 1946):

$$\frac{\text{film speed}}{\text{plane's ground speed}} = \frac{\text{focal length}}{\text{plane's altitude (above ground)}}$$

At the instant any particular section of the film is being exposed the image from the continuously open lens is sweeping across the open focal plane slit with the same speed and direction as the film. Although both the image and film are moving, they are stationary with respect to each other at the instant of exposure. The end result is a continuous strip of photograph 9-1/2 inches wide that may be as long as 200 feet.

Length of exposure is a function of slit width, lens opening, and film speed. Since film speed is fixed by the height and ground speed of the airplane, only slit width and lens opening are adjustable once plane height and speed are fixed for photographing a strip. This is not a serious limitation since excellent photographs have been made at low altitudes and high aircraft speeds with effective exposure times as long as 1/10 second. One special test permitted satisfactory photography 40 minutes after sunset with an exposure of 1/4 second (Katz, July, 1948).

Originally film speed had to be set manually for a given altitude and ground speed, and it was necessary for the airplane to conform closely to these limits during flight. Later, a photo-electric cell scanner was devised that automatically maintains synchronization very closely. According to Kistler, the light reflected from the ground or water surface passing under the plane

> "is used to excite the photo cells which produce a small electric current cycle representing a direct measurement of the plane's angular velocity. This angular velocity is directly related to ground speed and altitude. A magnetic impulse from the focal roller of the camera also produces an electric current cycle. The two cycles are balanced in a small amplifying unit. When the camera cycle falls behind the ground cycle a servo motor is energized which increases the film speed. When the camera cycle gets ahead the servo motor decreases the film speed. This synchronizing unit maintains synchronization very satisfactorily with changing airspeeds and rapidly changing altitudes (i.e., rough terrain). With automatic synchronization the slit width of opening must be varied to maintain constant exposure values as the film speed changes. This is automatically controlled by a mechanical connection between the servo motor film speed control and the slit control.

The matter of film speed synchronization has been explained in some detail since it is in this connection that a major limitation arises when Sonne photography is applied to forest measurements.

While of no great importance to forestry, it is interesting to note that there is no apparent limitation because of air speed to the use of the strip camera principle.

Speeds up to 1000 miles per hour have been handled from altitudes as low as 200 feet (Katz, July 1948. Kistler, 1946). This feature of extreme speed at low altitudes is of course of great military value.

It is in the matter of scale that the Sonne camera seemed to promise the most profitable applications for forest measurements. Photographs of great clarity have been made with representative fractions as large as 1/300. However, with large scales a restriction is imposed by the fact that for taller trees there is enough difference in the angular velocities of the tree top and bottom with respect to the moving camera to cause considerable blurring. This limitation will be discussed fully in the following section FACTS COLLECTED beginning on page 15.

Viewing a single continuous strip photograph provides no stereoscopic depth perception for height or depth measurements. Stereoscopic photographs are obtained by partitioning the camera's lens cone into halves and using one lens for each half. A small rotation of the lens turret moves one lens forward and the other backward with respect to the slit. Thus with the camera in a vertical position the forward lens photographs an object on one half of the film before the plane passes over it, while the same object is photographed again on the other half of the film after the plane passes over it. This gives the stereoscopic separation needed for the pictures to be viewed with a specially designed mirror stereoscope. The two lenses may be moved from a zero degree separation to a 20 degree to stereo lens angle to control parallax values. A five degree angle gives normal stereo values for the average observer (Kistler,1946)

Continuous strip photographs are made as standard black and white prints and as color transparencies. Color film had particular values in military reconnaissance and it seems to have certain advantages in forestry. A comparison of black and white and color is found under FACTS COLLECTED starting on page 15.

Equipment Used .

Continuous Strip Photograph: The photograph used in this study was supplied through the cooperation of the U.S. Naval Air Training Center at Pensacola, Florida and the Southern Forest Experiment Station of the U. S. Forest Service. The area photographed was the Escambia Experimental Forest of the Southern Station's Brewton, Alabama work center. The forest is located in second growth upland longleaf pine type of south Alabama.

This photograph is for stereoscopic viewing and provides two strips 4 5/8 inches wide running parallel along the same 9-1/2 inches wide film base. The total length of the film is 150 feet. This particular photograph is a color transparency on Kodacolor Aero Reversal film. A sample from the strip used is seen in figure 1 on page 67.

The stereo lens angle used was five degrees and film speed synchronization was apparently by means of a photo-electric scanner. Camera focal length was 100 m.m. Ordinarily one camera lens photographs ahead of the airplane and the other to the rear. In this case, however, one lens was pointed vertically downward while the other pointed ahead of the airplane. The stereoscopic view was just as easily achieved, and there was the added advantages of being able to measure displacement by simply scaling inward at right angles to the center line of the vertical strip photograph.

Stereoscope: A special mirror type stereoscope was furnished through the courtesy of the Chicago Aerial Survey Company, the original manufacturers of Sonne equipment. A home made mirror stereoscope with adjustable outer mirrors were used successfully, but the special viewer was more convenient for studying the transparency. The manufactured stereoscope incorporated binoculars for six power magnification, but it was unnecessary to use this feature because of the large scale of the photographs.

Since the photograph studied was a color transparency, a light table with reels at either end for handling the film strip was used in conjunction with the stereoscope. In the case of black and white photographs the picture is a contact print made in continuous strip. This would be viewed with reflected light from fluorescent tubes arranged under the housing of the stereo viewer.

Measuring Parallax Difference: A "floatingmark" comparator was developed by the Chicago Aerial Survey Company for measuring parallax difference with the special mirror stereo viewer, but this type of comparator was not available for the study. It was thus necessary to adapt the Harvard model parallax wedge principle of measuring parallax difference for use with the continuous strip film.[1] In effect, the standard wedge was divided midway between the converging lines, and one of these lines was then moved above the other without changing the distance between the lines. Also, since the stereo strips are fixed, the distance between the converging lines had to be accommodated to the absolute parallax of 0.365 inches.

The concept of absolute or total parallax and base length is unique in the case of the stereoscopic strip photograph. Since there is no fixed principle point as in individually exposed photographs, the absolute or total parallax is the distance between identical points on the strip pairs and is measured parallel to the line of flight (Kistler, letter 1949). This is also called the base length. A series of 32 such measurements at random points along the part of the film studied gave the mean base length or total parallax of 0.365 inches.

The parallax wedge finally adapted was drafted on cellulose acetate material and was graduated in dots, each

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[1] A discussion of parallax wedge measuring devices is found on page 55 of Appendix II.

of which corresponded to 0.0084 inches of parallax difference. A more accurate wedge could have been made by photographic reduction, but it was found that much larger errors than those of the wedge were introduced through scale variation and blurring. Hence, the wedge used was considered satisfactory and gave consistent readings with different operators.

Measuring Displacement: Some tree heights were measured by the displacement method. Since one of the stereoscopic strips was taken with a vertical lens, displacement was measured on it by scaling distances at right angle from the strip center line to tree tops and bases. A micrometer wedge reading up to 2.50 inches by 0.01 inch graduations was devised on cellulose acetate for measuring displacements.

Measuring Sample Plots: At first attempts were made to measure individual trees on plots of different sizes. Circles of appropriate diameter, inscribed in black ink on matted cellulose acetate and placed between the film and the light table, gave a convenient plot pattern. Since scale later proved to be highly variable, it would be necessary to have a series of such circular templates to correspond to the scale at various points on the film.

FACTS COLLECTED

The impression gained from a casual examination of a continuous strip photograph is that here must certainly be a source of precise and detailed information. The appearance of the film, particularly in the case of color photographs, is almost spectacular in the amount of qualitative detail to be found in some places. Visions of arm chair forestry deluxe are shattered, however, when the photograph is more closely examined and measurements are attempted. Close examination and measurements have revealed two serious deficiencies of pictures from present short focal length cameras. These shortcomings are the blurring that results from differential movement of larger objects and the great scale variation that comes with slight changes in altitude when large scale photographs are taken. Blurring and scale variations are treated in detail in the following two sections.

Blurring.

When first noted, the blurring was thought to be a result of tree movement during exposure. The appearance was similar to that of an object that has moved during an exposure with a conventional camera. While this probably did happen in some cases, the pattern of blur was repeated too often for movement to account for all of the distortion. Then, too, the blur extended to entire bands of the strip, in some instances affecting tree crowns and in others the ground. There are places where the tree tops are clearly defined while the ground is blurred. In other areas the reverse is true. Intermediate cases present a blurred ground surface, blurred tops of taller trees, and a clearly delineated intermediate crown level.

At first it was thought that the Sonne camera might lack the depth of field necessary to define a tall tree completely from top to base. However, applying depth of field formulae from Neblette's text it was found that even with large lens openings there would be no such effect. Although the exact lens stop used is unknown, it is unlikely that the opening exceeded f/3/5. With an f/3.5 opening everything over 64.2 feet from the camera would appear clearly to focus. With an f/2.0 opening, which is even larger than f/3.5, all things beyond 90 feet would be in focus. Since the lowest airplane altitude determined over any of the study areas was 215 feet, all trees 125 feet in height and under would be sharply defined so far as depth of field is concerned, even with an f/2.0 lens aperture. The tallest tree found on the study areas was only 70 feet high.

Correspondence with Kistler (March, 1949) and Colonel Goddard (March, 1949) indicates that the blurring is mainly a film speed synchronization effect. When the film is automatically synchronized, the electrical scanner picks its cycle from the strongest ground image. Thus in a well stocked area the image actuating the scanner would come mainly from crown canopy and the film speed would be adjusted accordingly. Since the tops of trees have a greater angular velocity with respect to the camera than the ground below them, the film will be moving too rapidly to define clearly the lower levels openings appearing from time to time in a heavy canopy. Similarly, in understocked areas the main scanner impulse comes from the ground. Tops of scattered tall trees will be blurred because the film will be moving too slowly for the angular velocity of their tops. If manual pre-setting of film speed were substituted for electrical synchronization, the effect would be no better. A fixed setting would not take into account changes in topography.

Kistler observes that the apparent depth of sharply defined picture varies with slit width and f/stop. However, he approximates that the clearly defined zone would be between 1/5 to 1/10 of the plane's altitude above ground. This would mean a sharpness zone of only 20 to 40 feet in the case of a plane at 200 feet. Colonel Goddard estimates approximately the same zone of sharpness. He states that "objects whose images would require a five (5) to ten (10) percent change in film speed to be in perfect synchronization, are recorded satisfactorily in spite of their being somewhat linearly distorted along the line of flight." Using the relationship that follows:

$$\frac{\text{film speed}}{\text{plane's ground speed}} = \frac{\text{focal length}}{\text{plane's altitude}}$$

it can be shown that at 200 feet of altitude a plus and minus change of 10 per cent in film speed with all other factors constant gives a sharpness zone of from 182 to 222 feet, or a spread of 40 feet. If the scanner were picking its cycle from the ground only, 200 minus 182, or 18 feet would be in the sharpness zone. If actuated from an intermediate crown canopy, the full spread of 40 feet would be available. On the film studied the sharpness zone seems to correspond closely to the relationship just discussed.

Effect of Blurring: Blurring makes height measurement of the taller trees almost impossible since the distorted top is indefinitely located in the stereoscopic view. If the ground vegetation and reproduction are to be studied they are often so indistinct that they cannot be identified. The net result is to make the Sonne photograph unreliable for most forestry work. In the case of plantations or young sapling stands where the depth of sharpness zone would be great enough to include the small trees being studied, continuous strip photographs might be used to advantage. In this case the image actuating the scanner would come only from the narrow height zone of smaller trees.

Scale Variation.

Kistler (1946) points out that to obtain large scale photographs for military reconnaissance, airplane altitudes were so low that small errors in altitude resulted in relatively large errors in percentage of altitude. In flying for landing beach photographs it was necessary for a plane at 200 feet to stay within 10 feet of the prescribed altitude if depth measurement were to be sufficiently accurate (Snyder and Frame, 1946). When automatic film speed synchronization was introduced more leeway was permissable providing a record was made during photography of film speed and altitude that could be correlated with the film index numbers. These index numbers are stamped at 8.15 inch intervals along the film margin. Records of film speed and altitudes are difficult to make and are seldom taken. If the photograph is made over land, ground measurement of distances between objects identifiable on the film may be used to calculate scale. The latter method was used to determine scale for the study areas discussed below under Applications to Mensuration.

If the airplane maintains a constant altitude, topographic changes still result in large scale variations even over gently rolling terrain. With the 100 mm. focal length camera the scale changes 0.25 feet per inch for every one foot change in the plane's altitude. At the low altitudes needed to give the desired large scale it is evident that percentage errors will be high. Assume, for example, the airplane is flying at 200 feet above the ground. If the ground rises 25 feet and plane altitude remains the same, scale will change from approximately 51 feet per inch to

45 feet per inch, a 10 per cent change on a linear basis. If areas were being measured for sample plots the change would amount to 19 per cent. These percentage changes would, of course, become errors of like amounts if the operator failed to realize that the scale had been altered.

If the Sonne camera were to be used in even relatively level country a large number of ground measurements would be needed for control. In rugged terrain continuous strip photography would be ruled out, at least for large scale pictures. Of course, higher plane altitudes would reduce percentage variation, but then scale would be so much smaller that there would be no advantage over conventional photography.

Applications to Silviculture and Management.

The most promising applications of continuous strip photography to silviculture and management are as follows: species identification of trees and shrubs; crown and stem relationships; tree location maps and stem counts; site evaluation; and plantation and reproduction studies. The findings in each of these categories are discussed below.

Species Identification: The writer had a general knowledge of the photographed area prior to receiving the field data taken on the specific areas that were studied. On the basis of this knowledge, identification could be made of longleaf (Pinus palustris), slash pines (pinus caribaea), flowering dogwood (Cornus florida), and sweet bay (Magnolia virgiana). Of the shrub species only gallberry (Ilex glabra) could be determined with some certainty. Oaks could be identified as a group only.

The field data confirmed the above determinations, but it did little to extend identification to other species. Of the oaks, only blackjack (Quercus marilandica) had a fairly consistent color and texture pattern. Southern red oak (Quercus falcata) was extremely variable in color, texture, and form, but the larger trees of this species could be recognized by their size and form alone. The other commonly occurring species were bluejack oak (Quercus cinerea), post oak (Quercus stellata) and persimmon (Diospyros virginiana). None of these had characteristic colors or patterns on the photograph. The tree specimens of tulip poplar (Liriodendrom tulipifera) found on the pictures seemed to have a consistent color and pattern.

Where the ground was not blurred, longleaf pine reproduction one foot in height was easily distinguished by its unique form. Slash pine reproduction was also identifiable as was small flowering dogwood from its characteristic yellow-green color. Oak reproduction was not distinctive.

In poorly stocked or completely open areas the grass and other small plants were usually sharply defined. Had it been possible to make detailed field comparisons in such areas, it seems very likely that good results might have been obtained in species identification. In such cases line-intercept and transect techniques for determining percentage of species composition in wild life and range studies might be applied successfully.

Crown and Stem Relationships: The most striking single feature of the strip photographs is the sharply defined detail of some of the tree crowns. On the pines individual needle clusters are apparent; in some cases the clusters are seen to be divided into groups of needles. The photograph, which was made in the spring, shows the new terminal growth or "candles" of the longleaf pine with unusual clarity. In some cases the staminate cones are visible. Crown vigor can also be assessed from the foliage density and, in this photograph color. In one area a group of slash pine were seen to have browning foliage. In this case the cause was normal needle cast in conjunction with new spring growth, but apparently insect infested trees with yellowing foliage could be easily spotted in color film.

Crown diameters could be measured if scale were known for the area in question. Even then the height of the maximum crown dimension would have to be measured so that scale corrections might be made. As indicated under Scale Variations on page 19changes in altitudes are sharply reflected in scale. For example, maximum crown width might easily be 50 feet above the tree base. With the plane at 250 feet above the tree base there would be nearly a 20 per cent decrease in the scale value from base to the point of maximum crown width. Since height measurements are erratic it would be difficult to determine the height of the maximum width in order to make the necessary scale correction. Of course, each tree would require a separate measurement to determine scale correction.

Along the outer part of the film strip some isolated trees are exposed from base to crown tip. This effect is similar to the view seen from a lookout tower. Near the tower only the crowns of trees can be seen, while more and more of the trunks become visible so trees further from the tower are viewed. In such cases of great displacement it is possible to make an assessment of log grade. Limbs, crook, and even some large defects are apparent where blurring doesn't interfere. Per cent of live crown to total height may also be found. The number of trees so exposed is small, however, and those which may be seen are often open-grown, low quality stems.

In well-stocked stands it is difficult, even with a stereoscopic viewer, to determine individual crowns and crown tips. Near the edges of the film the extreme displacement often superimposes crowns and stems into such a jumble that stem and crown features are largely obscurred or are unassignable to individual trees.

Tree Location Maps and Stem Counts: If difficulties resulting from scale variation can be resolved, continuous strip photographs may be used to prepare individual tree location maps for detailed silvicultural studies of understocked areas. A number of such maps were made and the time required to sketch a half acre plot at the 1/700 scale was approximately 20 minutes.

However, the stem counts are subject to an appreciable error, particularly in the better stocked areas. For example, of the total of 121 trees reported in the field data from the three study areas, only 99 appeared on the original overlays carefully drawn from the photographs. Most of the trees missed were four inches or less in diameter breast height, but in three instances 10 inch longleaf pines were completely overlooked. Many of these "misses" were anticipated where clumps of hardwoods were involved. With pines, too, it was almost certain that some crown clusters were composed of more than one tree, but the specific number couldn't be determined.

Site Evaluation: Aside from the limited area coverage, Sonne pictures seem to offer distinct advantages over conventional aerial photographs for site determination. Just as with regular photographs, site must be a relative classification; the gain from continuous strip would be from the larger scale. All of the principal criteria listed by Spurr (1948, p. 187) - topography, soils and geologic formations, vegetation, and total height - crown diameter ratio - are more evident on the large scale photographs, even when limitations of blurring and scale are considered.

Reproductions and Plantation Studies: In understocked areas where there was little blurring, reproduction and other small vegetation were seen clearly. In areas where there are few tall trees to change film speed synchronization to the upper crown canopy the Sonne camera could be applied to advantage. Changes in topography are accommodated by the automatic synchronizer; it is only when two levels are encountered simultaneously that the troublesome blurring occurs. Where the ground level is clearly defined, studies might be made of reproduction with reference to seed trees, ground cover types, size of stand openings, and site. The narrow coverage of the strip limits this since it is usually difficult to tell what trees were seed sources and what factors outside the strip are affecting the visible reproduction.

No plantations are included on the films studied. It seems evident however, that continuous strip photographs could be used to advantage in survival counts and other studies of extensive plantings. Blurring would not occur until tree heights exceeded the limits outlined on page 18 and excellent counts could be made on the regular pattern of a plantation.

Applications to Mensuration.

One of the principal advantages of continuous strip photography, its extremely large scale, is achieved at a sacrifice of area covered per flight strip. Thus, to be of practical value in forestry the Sonne photographs must be used in sampling woodland areas, and the amount of information derived from each strip must necessarily be larger and more precise than that from conventional pictures. This is apparent from the following example.

In the photograph studied the representative fraction varies, but an average value is approximately 1/700. Since the photograph is a stereoscopic strip, only half the 9-1/2 inch film base represents area actually covered. This means that the width of each flight strip is only about 270 feet. Allowing for 30 per cent side lap, 63 flight strips of 1/700 scale photographs would be necessary to cover the area represented in a single 9 x 9 inch aerial print at a conventional 1/15,840, or four inches to the mile, scale. This would require approximately 142 miles of flight strip and nearly 1300 feet of film for Sonne camera coverage. Clearly, large scale photography is confined to sampling techniques so far as forestry work is concerned. Similarly, continuous strip photography would have little if any value in the preparation of planimetric maps. A limited application might be made to timber type maps if an area were systematically covered with Sonne camera flight strips.

Height Measurements: Tree height measurements were made by means of the displacement, parallax difference, and shadow length methods. The shadow method was completely unsuccessful since the photograph used was made near midday and shadows were too short for accurate computations. The fact that longleaf pine crowns tend to be of a round form further complicated such measurements. However, there is reason to believe that in certain timber types shadow measurement might be the most accurate method of height measurement on these large scale photographs.

Height measurement by parallax difference and displacement were somewhat more successful, but the results are too erratic to hold much promise of the degree of precision that would be demanded. Results of these two methods are presented below.

1. Parallax Difference Method.

An adaptation of the Harvard parallax wedge, described fully on page 14 under Equipment Used, was employed to determine parallax difference. A minimum of five readings were made for each tree. At least a half hour elapsed between successive readings on the same tree. The mean of the parallax readings for each tree was used to compute height according to the formula

$$h = \frac{P \times H}{T}$$

where h = tree height

H = height of camera above tree base

T = total parallax or stereo offset

p = parallax difference

This formula is derived from the formulae given by Kistler in his 1946 publication. The geometry of continuous strip photography is considerably different than that for conventional photography; a full discussion of the relationship involved in height calculations is given in Appendix II on page 56.

Height determinations by means of parallax difference were made on selected trees in three separate areas of the photograph designated by the film index numbers as 0832, 0837, and 0920. Stand location maps in the form of overlay tracings of these areas were sent to south Alabama where personnel of the Southern Station made field measurements of height to the nearest half foot using an Abney level. A comparison of computed heights with corresponding field measurements is made graphically in Figure 2 on page29A A detailed comparison of all height measurement data is found in Table 2 on page59in Appendix II. Trees selected for height comparisons were those that offered the most favorable chance for the measurement of parallax difference and displacement. While additional height data might be enlightening it is unlikely that any increase in accuracy would be noted. An explanation of the study areas used for height measurements is found beginning on page 60 of Appendix II.

It is difficult to explain the random scattering of the errors in height measurement since no pattern or trend is evident in all cases. Results might have been better with the so-called "floatingmark" comparator, but even so, when the tree top is blurred accuracy would be impossible

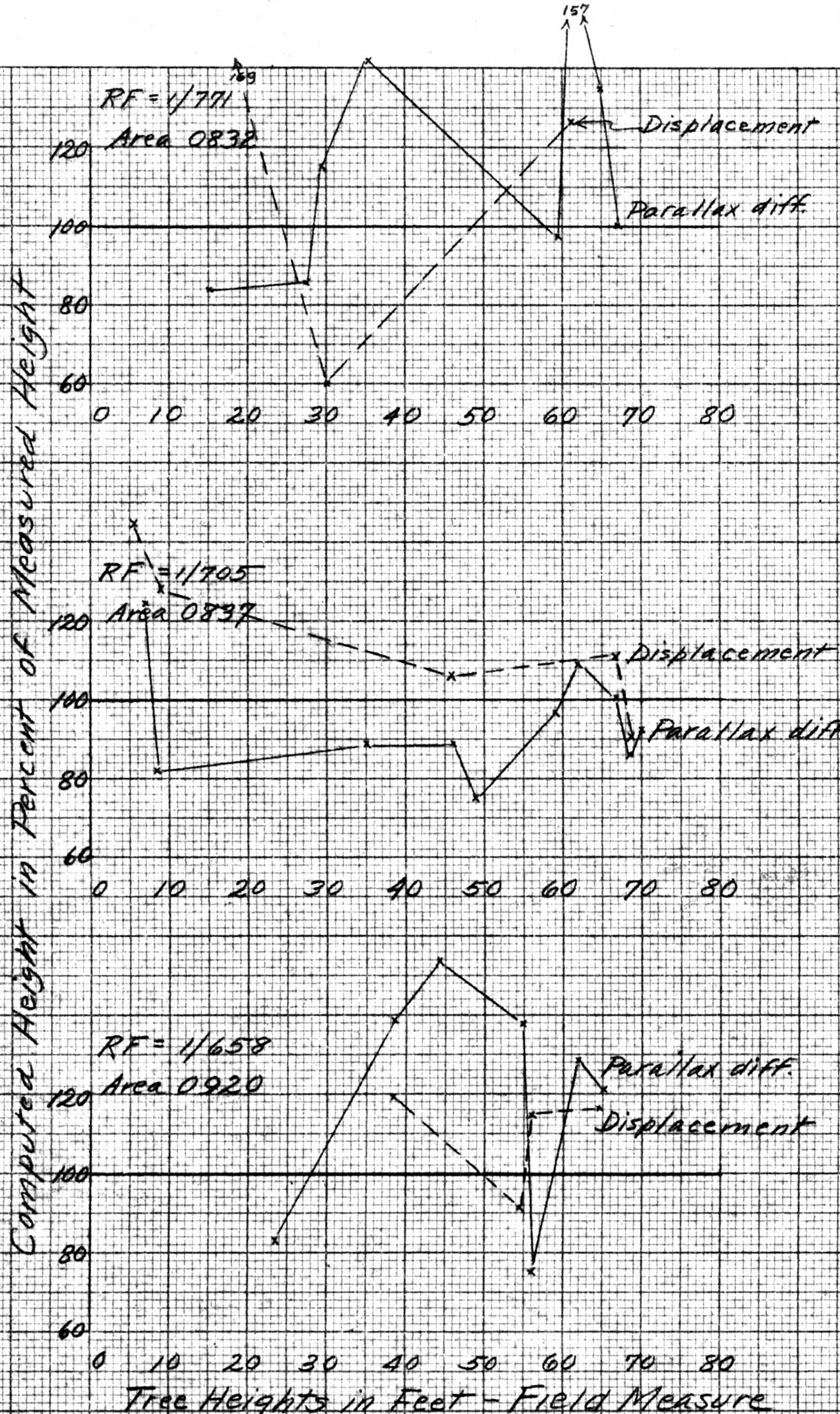

FIGURE 2. Computed tree heights as a percentage of heights measured in the field with an Abney level. Each point on the curves represents a single tree.

with even the best equipment. The most obvious conclusion here is that tree height measurements on this continuous strip photograph are not accurate enough to be used with a sampling technique.

2. Displacement Method.

The results of height measurement by the displacement method are shown in Figure 2 on page 29A. A tabular comparison of displacement method results appears in Table 2 on page 59 of Appendix II. Only a small percentage of trees along the outer edge of the strip are exposed enough to show the crown tip and base that are necessary for measurements. Barely half the total trees selected for parallax measurement could be measured for displacement. Except for the smaller trees where measurement errors are reflected as high percentage variations, the results are somewhat more accurage. The more accurate measurements are those for trees whose bases and crown tips are most clearly defined in the picture. Still, the accuracy achieved with the displacement method is far from satisfactory.

Ocular Limit to Height Measurement: An additional deterrent to the use of the parallax method is the limit of the human eye to detect parallax difference. So far as can be determined the maximum difference that can be detected without elaborate optical equipment is between 0.15 and 0.20 inches.[1] The largest difference read in this study was

[1] A more detailed discussion of limitations of stereoscopic depth perception appears on page 63 of Appendix II.

0.163 inches and this was done with difficulty. With the Harvard wedge about half the total wedge distance, or approximately 0.20 inches, is the usual limit. The Abrams Contour-Finder, which operates on the floating dot principle, has a maximum calibration of 4mm. difference, or 0.158 inches. Thus it seems reasonable to assume that 0.20 inches is near the maximum of parallax difference that can be read.

With a 0.20 parallax difference and an altitude of 200 feet the tallest tree that can be detected is 70.8 feet; at 250 feet the maximum height is 88.5 feet. While this limit would be large enough for some stands it would certainly impede the general application of present Sonne equipment to forest stands.

Diameter Measurements: The lower trunks of some trees along the outer part of the strip are clearly visible. A micrometer wedge[1] reading to the nearest 0.001 was used to measure diameters at breast height of such trees on the study area. A comparison of these measurements with field data for the seven suitable trees is made in Table 1 on page 32. The procedure necessary to locate the diameter breast high point is explained on page 65 in Appendix II.

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[1] The wedge used was Timber Survey Aid No.2. from the Pacific Northwest Forest and Range Experiment Station.

TABLE 1

TREE DIAMETERS AT BREAST HEIGHT FROM PICTURE MEASUREMENTS

COMPARED WITH FIELD MEASUREMENTS

Area Index Number	Tree No.	DBH Inches, Field Data	DBH Inches, Photo Measure	Photo Measure as % of Field DBH
0832	17	15.2	20.8	136.6
0832	18	12.6	14.6	116.0
0832	20	11.6	17.7	152.6
0837	12	12.8	16.2	126.5
0837	21	7.0	9.9	141.5
0920	28	11.7	16.5	141.0
0920	31	11.4	18.4	161.5

Computed diameters range from 16 to 62 per cent greater than the corresponding field measurements. The most probable source of error is the usual tendency for the ground zone to be slightly blurred; this would result in measurements larger than the true ones. Other possible sources of error are constant errors by the wedge operator or an inaccuracy in the wedge used. The micrometer wedge employed was checked against several other makes of wedges and it corresponded to them as exactly as the eye could determine. If the tree trunks measured were not blurred it might be possible to measure them with a mechanical vernier micrometer such as is used on microscope stages. However, this refinement does not appear profitable since diameter measurements in general are impractical on present Sonne type photographs.

Black and White and Color Photographs Compared.

In general the color transparency should be more useful in forestry than black and white photographs. With hardwood especially color aids in species identification and in the separation of individual trees. Color is not an infallible guide to species identification, however. Even when the film has been correctly exposed the foliage of some species, such as southern red oak (*Quercus falcata*), has a wide range of color and texture. It would not be easy to make a color chart that could be used for species recognition. In addition, color may vary as a result of underexposure, stray cloud shadows, and the varying light reflecting quality of foliage ruffled by wind.

The black and white film available for comparison was limited to a single strip taken in the Central States hardwood type. The writer has no knowledge of the specific area photographed. In general, the definition of objects seems sharper than with color, but the same troublesome blurring of ground and tree tops is present. Aside from the extra cost involved color film appears best adapted to forestry purposes.

Even when costs are considered color film is not ruled out for forestry uses. On the basis of cost data furnished by the Eastman Kodak Company the Kodacolor Aero Reversal film would cost approximately $2.06 per foot to $0.77 per foot for standard infra-red (black and white pictures) film and prints. Both estimates include an allowance for finishing and, in the case of black and white, printing. The calculations of film costs are included in Appendix II on page 66. Since film cost is a minor part of the total expenditure for an aerial photographic job, the difference in price should not prevent the use of color film when its advantages are considered (Colwell, 1949).

CONCLUSIONS

Present Sonne type aerial cameras have an extremely limited application to forestry. Speaking of Sonne strip photography, Fuller (1949) states that "it has of course the elements of ultimate accuracy but could not at present be used for measurement of tree heights in general or wood volume." Kistler (1949) also points out that not too much accuracy should be expected in areas where there is not exact scale control from ground measurements.

A limited application of present equipment can probably be made in sampling understocked forest areas and large plantations. Where qualitative samples or enumeration data are required the Sonne camera with automatic film speed synchronization may be used, provided that the subject is not partially obscured by a tree crown canopy and the subject's height doesn't exceed approximately 1/5 the plane's altitude.

The development of a Sonne camera adapted to forestry work seems entirely practicable. Colwell (1949) proposes a possible solution to the blurring problem by using a stereoscopic strip camera with a longer focal length. This would permit photography at the same advantageously large scales but from a higher altitude. Incidentally, this could also eliminate the ocular limitation to height measurement discussed on page 30.

Colonel Goddard (1949) states that "evaluation of various problems in forestry utilizing strip stereoscopic photography is entirely feasible. The time and flight requirements including altitude, camera focal length, and lens parallactic angle [i.e., lens stereo angle (Kistler, 1946)] however, must be planned in advance of the flight for optimum results." Apparently, then, Sonne cameras can be developed with any required focal length.

The possibility of making stand rather than tree volume measurements has been suggested by Colwell (1949). This approach was not investigated, but it would appear to be the best means of using present type strip photographs if they are to be used at all.

A Sonne camera adapted to forestry work would have certain advantages in addition to those obtaining from the large scale. For example, more flying weather would be available. The lower plane altitudes would permit photography under cloud and haze conditions which prohibit exposures from the greater altitudes required in conventional photography. As previously pointed out, there is greater latitude in exposure time; this fact would permit photography under adverse light conditions. In this connection it is of interest that standard type shutter cameras are being developed which apply the Sonne principle of image motion compensation (Katz, July 1948). The entire film magazine moves in synchronization with ground speed during the exposure period, and then returns to normal magazine position after exposure.

In summary, present Sonne cameras can have but limited use in forestry work. When suitably adapted it is probable that continuous strip photography will be a useful supplement to the standard aerial photographs that are now so widely used.

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Nowicki, Albert L. "Elements of Stereoscopy", Manual of Photogrammetry, 304 - 320, Pitman Publ. Corp., New York. 1944.

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Van Keuren, V. Personal communications of February 18, 1949, and March 14, 1949.

APPENDIX I

COPY

UNIVERSITY OF CALIFORNIA
College of Agriculture
Agricultural Experiment Station

School of Forestry
Berkeley 4, California

February 9,1949

Mr. Arnold L. Mignery
School of Forestry and Conservation
University of Michigan
Ann Arbor, Michigan

Dear Mr. Mignery:

Your letter of February 6 has just been received, in which you outline some interesting problems in connection with the use of Sonne photography for forestry purposes in southern Alabama.

Regarding the difficulty of blur of both tall tree tips and the ground, this is, of course, an inherent difficulty which to my knowledge cannot be overcome with the conventional Sonne camera. As you know, the speed of the film during photography is so adjusted that its angular velocity past a slit is commensurate with the angular velocity at which the plane is flying over the ground. At the scale of photography which you say you are using and with a focal length of only a little over four inches on the Sonne camera, the altitude of photography probably was only about 300 feet above the ground. Accordingly, trees even a hundred feet in height will have a much greater angular velocity than will the ground itself, and hence will have a blurred image. Probably in this case, adjustment was made for a datum which was about midway between the tops of the tallest trees and the ground itself, thus giving a blurred image at both of these levels.

A possible solution to this difficulty is to use a stero strip camera with a much longer focal length, thus permitting photography at the same scale as you were using, but taken from a much higher altitude. Such a camera has recently been developed by the Army Air Forces, I am told, and has been very successfully tested at Wright Field. If you wish to inquire as to its use, I would suggest that you contact Colonel George W. Goddard of the Army Air Forces at Wright Field who has charge of all work on experimental aerial photography. Very possibly much of the information that you seek is highly classified, but an inquiry might yield some very interesting informatioh.

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A reason other than the above for the difficulty which you report of a blurred ground image probably lies in the fact that shadows cast by the trees conceal much of the ground detail. In this connection, color photography may remedy the difficulty, if it is possible to make good black and white prints from the color photos through a filter which exposes primarily for blue wave lengths at light. This is pure theory on my part, but is based on the fact that most of the light reflected from shadows on the forest floor to the camera is from the blue and of the visible spectrum. Accordingly, prints made with the filter indicated would permit bringing out details in the forest floor without grossly overexposing the tree crowns themselves. Experiments along this line are now being undertaken at the U.S. Naval Photographic Intelligence Center in Washington, D.C.

As for your comment that color photography is of doubtful value, especially when expense is considered, I would question this because at least during World War II color film cost only about twice as much as panchromatic film, and, in any case, cost of film and of processing need constitute only a very small proportion of the total cost of procuring the photographs. Color photography should prove especially promising for low altitude work where filters need not be used to penetrate haze. Hence, it should be more successful for Sonne photography than for certain other types of photography used for forestry problems.

The difficulty of making tree-height measurements is quite understandable because both the ground and the tree tops are blurred in the type of photography which you used. This is a further reason for maximum detail in shaded areas of the forest floor. As for making volume estimates, it may be that much more than tree heights and crown diameters must be determined as experience in the West has indicated that the ratio of crown diameter to d.b.h. shows a much wider variation than has been indicated by certain experiments in the East. Stand rather than tree volume tables appear best here.

You are no doubt familiar with the work which Mr. Lewis R. Grosenbaugh of the Southern Forest Experiment Station has done with Sonne photography. He wrote me more than a year ago regarding its use in mixed delta hardwood stands of the South. In case you are not familiar with his work, I would strongly recommend that you check with him as to his findings.

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If I can be of any further assistance to you please let me know. In any case, I will be most interested in your results, and would appreciate hearing from you as to where and when your master's thesis on this subject will be published.

Very sincerely yours,

Robert N. Colwell
(signature)

Assistant Professor of Forestry

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EASTMAN KODAK COMPANY

ROCHESTER 4, N.Y.

March 9,1949

Mr. Arnold L. Mignery
School of Forestry and Conservation
University of Michigan
Ann Arbor, Michigan

Dear Mr. Mignery:

Thanks for your inquiry of March 2.

Infrared Aerographic Film is normally used for aerial surveys of forests, but possible color film does have a distinct advantage for tree species identification.

The 9-1/2" x 150 ft. Kodacolor Aero Reversal Film,N No. CR-1623, is priced at $270.20 list plus $27.02 tax per roll. You may perhaps prefer a shorter length for experimental purposes, and we would suggest 9-1/2" x 40 ft., No. CR-1621, priced at $74.00 list plus $7.40 tax per roll.

Gelatin Filters are necessary for use with color film, and the 5" square filters are supplied at the additional price of $13.50 per set.

The Chemical Kits for processing color film are supplied in two sizes. The 1-1/2 gallon size is priced at $5.00 list each, and the 4-1/2 gallon size is priced at $11.80 list each. We understand that one of each size is normally required to process the 40 ft. or 75 ft. length of film.

We want to mention that the chemical contains 5% or more of an aromatic amine which may cause irritation if the powder or its solution comes in contact with the skin or open cuts, or if its dust is breathed. We suggest you use rubber gloves to handle the product,and avoid breathing its dust. We will not be responsible for any skin or other ailments caused by this product.

Infrared Aerographic Film, 9-1/2" x 150 ft., Identification No. IR-1623, is priced at $77.20 list plus $7.72 tax per roll. If a shorter length is desired

COPY

for experimental purposes, we would suggest the 9-1/2" x 40 ft. roll, Identification No. IR-1621, priced at $22.55 list plus $2.25 tax per roll.

We do not have either of the films available for immediate shipment, and inasmuch as they are not stocked by Kodak dealers, it would be advisable for you to place an order with your dealer at least 60 to 90 days in advance of your requirements.

We appreciate your interest, and trust you will feel free to write us at any time we can be of further assistance.

Yours very truly,

EASTMAN KODAK COMPANY

LEGoda
(signature)

Government Sales Division

LEGoda:CQ

COPY

CHICAGO AERIAL SURVEY COMPANY

332 South Michigan Avenue
Harrison 7-8360
Chicago 4

January 20,1949

Mr. Arnold L. Mignery
932 Heath Court
Willow Run
Michigan

Dear Sir:

In reply to your letter of January 18, we are obliged to inform you that at present the stereoscopic viewer and measuring comparator for Sonne strip photography is for approximate results only and accurate for certain measurements under very strict limitations. It has of course the elements of ultimate accuracy but could not at present be used for measurement of tree heights in general or wood volume. For instance the photographs to be measured must have at least two datum bases - say level water. The height of an object not more than twenty feet. It is possible then to obtain fairly accurate profile measurements only. You are, therefore correct in your statement of the limitations of its present use. It is largely a reconnaissance tool and gives accuracy only under elaborate and specific conditions.

Mr. Kistler you speak of, is no longer with our company, but would be glad no doubt to answer your questions. His address is P. S. Kistler, c/o Seaboard Oil Company,Cody, Wyoming.

We would be glad to have you come in for a visit but believe it would not pay you for a special trip.

A source of excellent information on all phases of viewing and measurement on strip photography would be -

Commander Victor Van Keuren
c/o Photo Interpretation Centre
U. S. Navy
Anacostia, Maryland

He has been in charge of the use of these instruments and his department accumulated wide and thorough experience on the subject and should be able to answer your questions fully.

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We are glad to have you get acquainted and use the instrument. When you are finished it may be returned by express.

Very truly yours,

CHICAGO AERIAL SURVEY COMPANY

E. W. Fuller
(signature)
Pres.

EWF:RS

Headquarters

AIR MATERIEL COMMAND
Wright-Patterson Air Force Base
Dayton, Ohio

MCREXF6/DJG/mmt

Subject: Continuous Strip Photography in Forestry Studies.

To: School of Forestry and Conservation
University of Michigan
Ann Arbor, Michigan
ATTN: Arnold L. Mignery

1. The effect of blurring noted on the continuous strip photograph is a result of poor synchronization between the passage of the image across the focal plane and the tree-top images. If the photograph is scrutinized carefully, it will be observed that at some level below the blurred tree-top images other images are not blurred. It was for this level that the camera was actually synchronized at the time the camera recorded this section of the photographic strip.

2. Theoretically, the film can be synchronized for only one level of objects it records. Actually, objects which were slightly above or below this one level are recorded satisfactorily and can be fused stereoscopically for height measurement purposes. Objects whose images would require a five (5) to ten (10) percent change in film speed to be in perfect synchronization, are recorded satisfactorily in spite of their being somewhat distorted linearly along the line of flight.

3. Another condition which could have been solely or partially responsible for the blurred effect is the requisite that the object must be stationary (or nearly so) during the time interval existing between the recording of the foreward and aft lenses. If this condition does not prevail, stereoscopic fusion will be impossible.

4. From the above discussion, it can be concluded that evaluation of various problems in forestry utilizing continuous strip stereoscopic photography is entirely feasible. The time and flight requirements including altitude, camera focal length, and lens parallactic angle,

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Ltr AMC to University of Michigan, "Continuous Strip Photography in Forestry Studies"

however must be planned in advance of the flight for optimism results. Continuous strip photography is a special purpose type of photography and when conditions dictate its use, results should be very satisfactory or even spectular as regards certain phases of evaluation.

FOR THE COMMANDING GENERAL:

GEORGE W. GODDARD
Colonel, USAF
Chief, Photographic Laboratory
Engineering Division

SEABOARD OIL COMPANY
of Delaware
200 North Wolcott Street
Post Office Box 2289
Casper, Wyoming

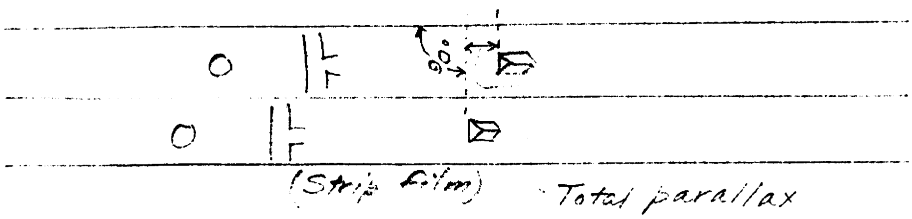
March 9, 1949

Dear Mr. Mignery,

I have your letter of Mar. 2 and will be very happy to help you in any way I can.

To first take up the problem of the Navy photos where the lens angle and scale only are known:

By measuring the total parallax (this must be done very carefully) and dividing that value into the altitude, the dh/dp value can be obtained (height per millimeter of parallax measured).



For instance at 250' alt. with 5° angle the total parallax should be about 9mm. Then $\frac{250'}{9} = 27.8'$

The dh/dp value is 27.8' which means for every mm. of parallax measured on the photo you have 27.8' of vertical height.

Since the Navy cameras are about 100 mm focal length (check the particular camera if possible) your scale of 1" = 60' to 65' means that the plane flew at an altitude of about 240' to 260'.

You are correct in assuming that the 20' limitation on measurement is not a constant. It varies with altitude. As you have already observed this is due to the inability of getting the tree tops and ground sharp at the same time if the tree height is too great. The 20' figure is approximate and varies with photo conditions (slit width, f stop, etc.) A better approximation would be between 1/5 and 1/10 of plane altitude.

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When the film is automatically synchronized the scanner picks its cycle from the strongest image and would jump from tree tops to ground in clear areas.

Service pictures are frustrating to work with because the pilots and photographers are not familiar with or are indifferent to the photogrammetrist's problems and complete accurate data is never available unless you oversee the operation completely or give the whole job to a commercial concern.

I would suggest that you do not expect too much accuracy on these particular photos in areas where you do not have exact scale control from ground measurements.

I hope these comments will be of help to you. Please do not hesitate to write me again if I can enlarge on the above or further clarify any details for you.

Sincerely yours,

P. S. Kistler
(Signature)

U. S. NAVAL PHOTOGRAPHIC INTERPRETATION CENTER

U. S. NAVAL RECEIVING STATION

Washington, D. C.

February 18, 1949

PIC/F44-2
ACL:hbm

Serial:

Dear Mr. Mignery:

In response to your letter of February 6, 1949, I must report that there is no comprehensive volume covering the use or assessment of continuous strip aerial photography. Photogrammetric considerations of strip photography are generally limited by the fact that such supplementary information as rate of film speed, aircraft ground speed and flying height are usually lacking or incorrectly recorded. Further, where considerations of water depth are concerned, additional information must be known on aircraft heading and wind direction.

To assist you with your investigation, we are enclosing herewith one copy of "Continuous Strip Aerial Photography" by P. S. Kistler as taken from "Photogrammetric Engineering," June, 1946.

Hoping that this information will help you with your initial investigation and that you will not hesitate to write to us at some future date regarding the specific detail or details of Sonne stereo measurement with which we have had considerable experience,

Yours very truly,

V. VAN KEUREN
Chief Engineer
(signature)

Encl: (1)

U. S. NAVAL PHOTOGRAPHIC INTERPRETATION CENTER

U. S. NAVAL RECEIVING STATION

Washington, D.C.

March 14, 1949

ENG:S:hbm

Serial: 132

Mr. Arnold L. Mignery
School of Forestry and Conservation
University of Michigan
Ann Arbor, Michigan

Dear Mr. Mignery:

This is to acknowledge receipt of your letter of 2 March 1949 and to answer your questions concerning height and depth measurements using Sonne photography.

As you have noted, the limit on water depth measurement is in the vicinity of 20 feet. There are several factors that determine this limitation such as water clarity, illumination, camera focal length and altitude of the aircraft. Beyohd 20 foot depths results are not accurate and measurements become questionable. This condition exists because of the afore stated factors and is not directly the result of any theoretical limitations.

I can see, however, no reason why height measurements are limited to 30 feet under standard operating conditions using a 100 millimeter focal length lens and a flying height of 200 feet above datum.

In the December 1948 issue of Photogrammetric Engineering there is an excellent article on underwater depth determination and I am quite sure you will find some helpful references at the conclusioh of this article.

It is hoped that your questions have been answered satisfactorily and that you have been assisted in your investigations.

Very truly yours,

V. VAN KEUREN
Chief Engineer
(Signature)

APPENDIX II

PARALLAX WEDGE MEASURING DEVICES

Spurr (1948, p. 143) describes the principle of the Harvard model parallax wedge as follows:

"The wedge consists of two diverging rows of dots, separated by a distance approximately equal to the image separation produced by the stereoscope under which the device is used. Each pair of dots (one in each row) is spaced 0.002 inch (or other equal increment) further apart than the preceding pair. When placed over the photographs under a stereoscope, portions of the two rows fuse stereoscopically and appear as a single row of dots slanting downwards through the stereoscopic model. The dots provide a sequence of reference marks of fixed vertical intervals which may be shifted about in the model and against which objects may be compared in elevation...."

A more detailed discussion entitled "Parallax Wedge Measuring Devices" by Spurr is found in Photogrammetric Engineering for 1945, volume 11, pages 85 through 89.

PARALLAX DIFFERENCE COMPUTATIONS

The geometry of the Sonne camera is shown schematically in Figure 3. From this figure the basic geometric relationship given by Kistler (1946) become apparent. Some of the formulae derived are as follows:

(1) $$\frac{h}{1/2\ P} = \cot\ a/2$$

which gives

(2) $$h = \frac{P}{2}\ \cot a/2$$

also

(3) $$\frac{P}{p} = \frac{H}{F}, \quad P = \frac{p\ H}{F}$$

Substituting for P in the second formula

(4) $$h = p\frac{H}{2F}\ \cot a/2$$

In all the above

a = Stero lens angle

H = Altitude of camera above datum

F = Focal length of camera

p = Difference in parallax on the photograph

P = Difference in parallax on the datum plane

h = height of tree

From Figure 3 it is also seen that $\cot a/2 = \frac{F}{T/2}$. Substitute this in the formula (4) to give

$$h = \frac{p\,H}{2\,F} \times \frac{F}{T/2}$$

which reduces to

(6) $$h = \frac{p\,H}{T}$$

This is the formula used for height calculations since H was known from a comparison of ground— photograph measurements and p and T, the total parallax, were measured directly from the photograph.

To understand the geometry of the continuous strip photograph it must be remembered that a line of sight projected from the focal plane slit through either lens makes a constant angle with respect to vertical objects as the airplane moves forward. Hence the height change per unit of parallax is constant for a given altitude and stereo lens angle.

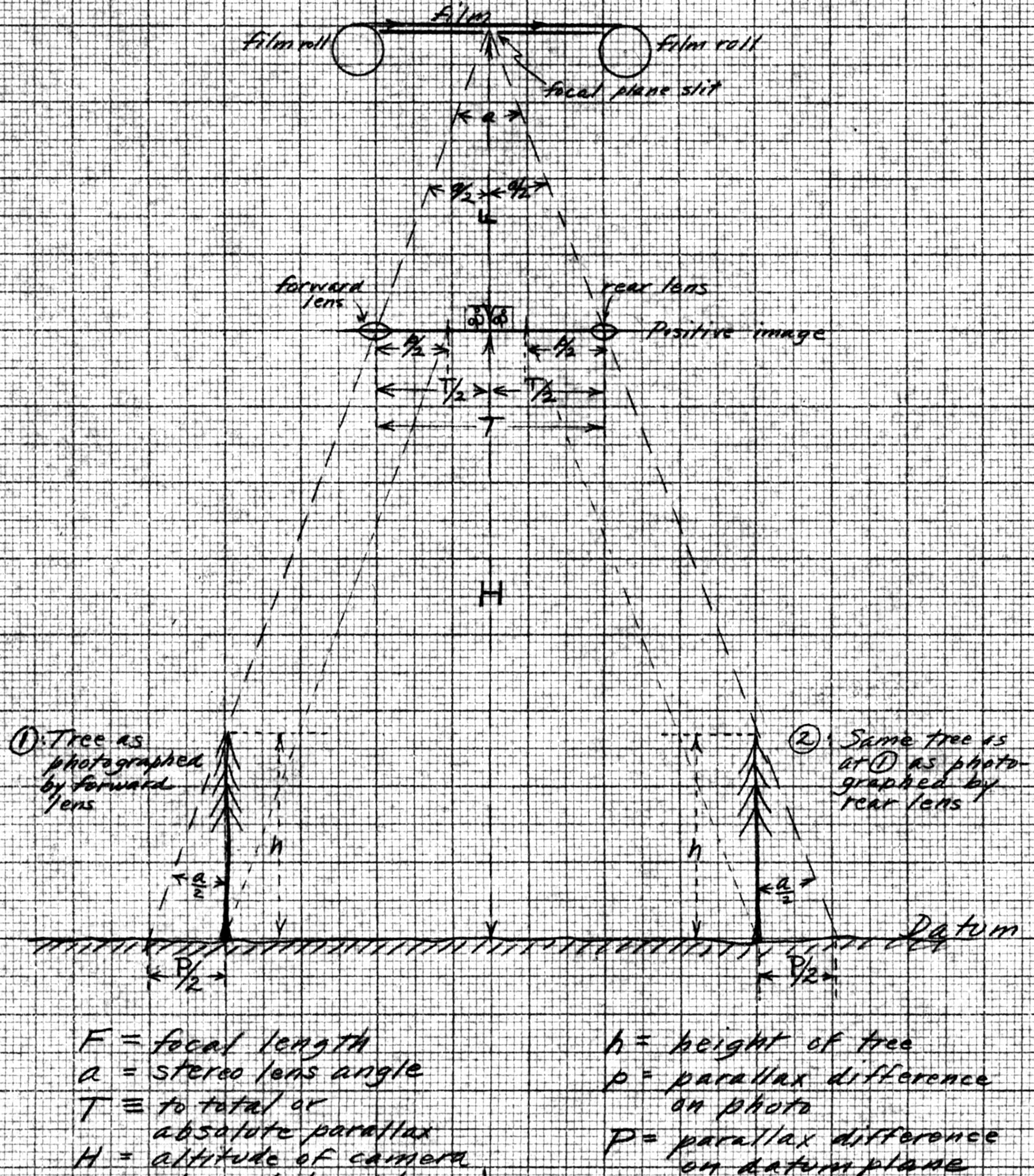


FIGURE 3. Schematic diagram of Sonne camera

TABLE 2

COMPUTED TREE HEIGHTS COMPARED WITH FIELD MEASUREMENTS

Area Index Number	Tree No.	Height in Feet Field Data	Computed Height, Feet: Displacement [1]	Computed Height, Feet: Kistler's Formula
0832	1	35.5	---	51.2
"	7	65.0	---	87.4
"	8	67.0	---	67.1
"	15	59.5	---	58.1
"	16	27.5	---	23.6
"	17	----[2]	78.6	113.0
"	18	----[2]	83.7	82.5
"	20	60.5	76.5	95.3
"	24	29.5	17.4	34.0
"	25	15.0	25.4	12.5
0837	9	68.5	62.0	58.2
"	12	67.0	74.5	67.6
"	13	62.0	---	67.6
"	18	70.5	---	65.2
"	21	46.0	48.8	41.1
"	24	7.3	10.5	8.9
"	26	8.6	11.0	7.0
"	30	59.0	---	57.0
"	31	35.0	---	31.0
"	38	49.0	---	36.1
0920	8	56.0	64.5	41.8
"	10	23.5	---	19.5
"	15	62.0	---	79.5
"	17	44.5	---	68.5
"	28	65.0	76.2	78.5
"	31	55.0	49.8	76.1
"	32	38.5	45.7	53.5

1 --- indicates measurement was impossible

2 No field data available

DESCRIPTION OF STUDY AREAS

The locations of the study areas are shown in Figure 4 on page 62. Areas are designated by the film index number which appears on the margin of that part of the picture in which the area occurs. As previously explained, stand maps were traced from the picture and were used in the field for identifying the trees to be measured.

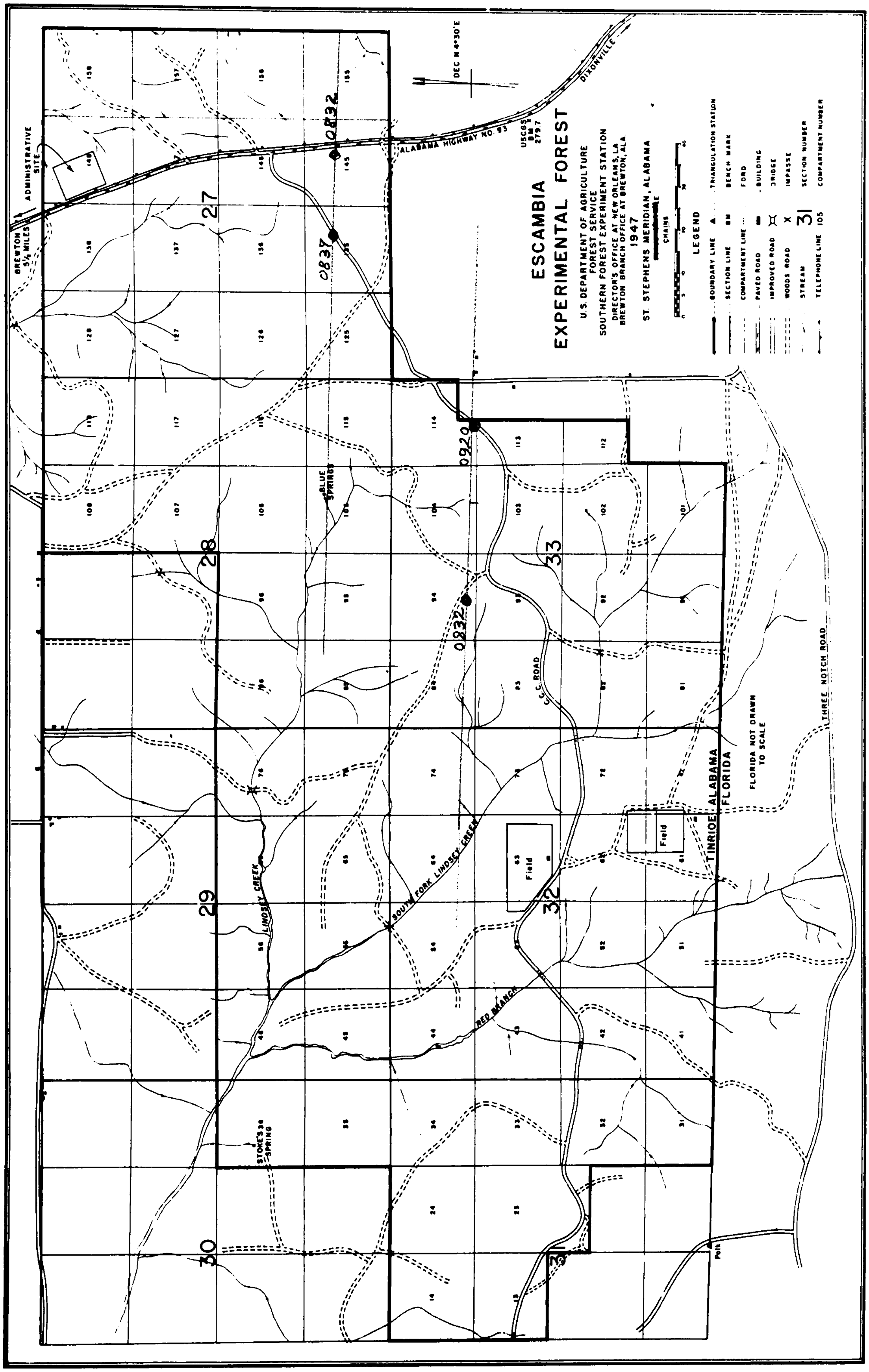
Areas were located on the basis of their suitability for height measurement, the variety of tree species present, and accessibility for field work. Each tree was identified as to species and a d.b.h. measurement was made if the stem was past the reproduction stage. Height measurements were made for selected trees on areas 0832, 0837, and 0920. The number of height measurements were limited in order to reduce the field work requested of the Brewton Branch personnel However, it is thought that an adequate number of trees and range of height classes were included to indicate the nature of results that may be expected from continuous strip photographs. Area 0932 was used for species identification only.

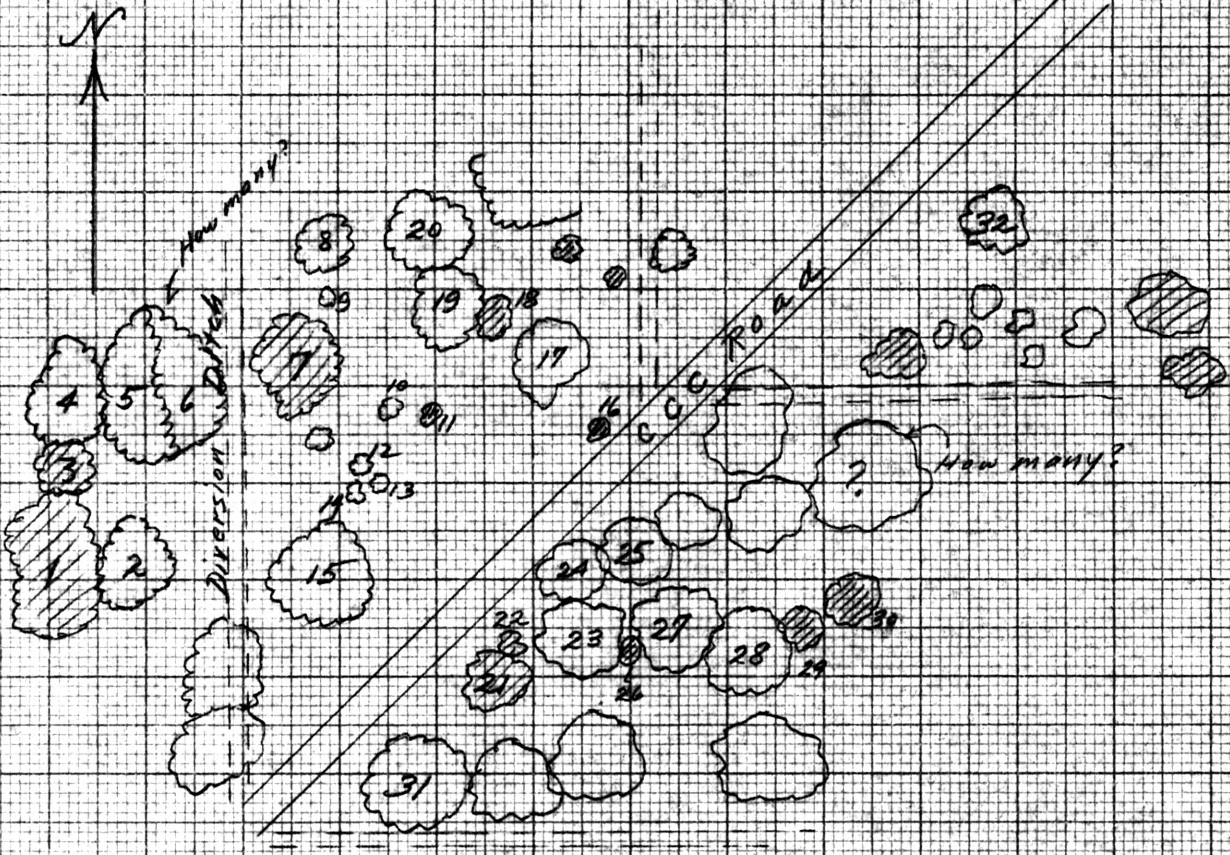
The number of trees included on the various areas, together with the scale of photography (computed from ground measurements) in each case is shown in the following tabulation:

Area Index Number	Number of Trees	Scale Ft./inch	R. F.
0832	27	64	1/771
0837	47	58	1/705
0920	37	55	1/658
0932	38	55	1/658

The field tally sheets are retained in the personal files of the writer. Figure 5 on page62A is an example of the type of stand location map used in the field work; the study area at index 0920 is shown. This map is a tracing made directly from the Sonne photograph. The continuous strip photograph, the property of the Southern Forest Experiment Station, is stored at the Brewton, Alabama branch.

Figure 4 LOCATION OF STUDY AREAS





Area 0920 Compartment 114

Scale: 1" = 55 ft.

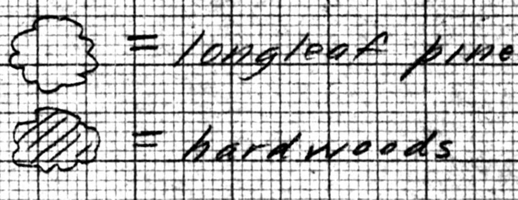


FIGURE 5. Example of overlay tracings used as stand maps for tree locations in field work.

OCULAR LIMIT TO HEIGHT MEASUREMENT

Specific information is lacking with regard to a method of computing the maximum parallax difference that can be detected. The maximum of approximately 0.20 inches discussed on page 30 is a practical limitation for stereoscopes available for most forestry work.

In his discussion of the elements of stereoscopy Nowicki makes the following comments that have some bearing on this problem:

> In aerial mapping operations involving the use of stereoscopic instruments, it will be found that visual acuity is dependent not only upon the inherent limitations of the instruments used and upon the physical nature of the light but also upon the physiological state of the individual....Because of the number of complicated biological factors thus involved, it is very difficult to establish or confirm limits of visual acuity.......
>
> It has been shown that there is a definite limit (20 seconds of arc) to the difference between the two converging angles of fixation upon an object. Since limits would be the equivalent to a minimum measurement of differences of elevation of two objects approximately 0.004 inches (i.e., without magnification). At a scale of 1/20,000, differences of elevation of seven feet or more can be determined by the above process, but a difference of less than seven feet could be determined only by means of some type of magnifying apparatus.......
>
> Artificial enhancement of the power of stereoscopic vision can be obtained by increasing the virtual base-line (i.e., interpupillary distance) or by the introduction of a magnifying optical instrument......

Apparently, there may be some way of overcoming the limitation on maximum parallax difference that can be detected. Use of six power magnification did not help readings with the continuous strip stereoscope used for this study. But even though the parallax difficulty were resolved, there is still the matter of blurring; with tree tops or ground level poorly defined, no real accuracy could be expected.

TECHNIQUE OF DBH MEASUREMENTS

The distance from the tree base to the point representing diameter breast height varies with camera altitude and the displacement of the tree from the center of the strip photograph. The d.b.h. point can be computed from a simple geometric relationship similar to that used to measure tree heights by displacement.[1] The proportion used is

$$\frac{H}{D} = \frac{4.5}{X}$$

In this case the d.b.h. point is fixed at 4.5 feet, D is measured at right angles from the center line to the tree's base, and H is known from previous calculations of scale. The unknown distance X is then computed and measured from the tree base toward the tip to fix the d.b.h. point. Straight line graphs were set up for each study area since H differed in all cases. The d.b.h. point was then determined by measuring D from the picture, and next, using the curve that applied to the area, X was found for the individual tree. With the necessary point thus established, the photographic diameter was measured with a micrometer wedge and this reading was converted to the ground scale involved.

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[1] See the discussion given by Spurr in "Aerial Photographs in Forestry", pp. 78-79.

COMPARISON OF COSTS OF BLACK AND WHITE AND COLOR FILM

This comparison is necessarily limited to the cost of materials used for each process; it is based mainly on a letter from the Eastman Kodak Company in which certain costs were quoted (See Appendix I, page 44). The cost of developing and printing the black and white film are estimated at 20 cents per foot. No data was obtainable for this process, but it is known that the printing is a continuous machine process and that 9 5/8" contact paper may be obtained in rolls for under five cents a foot. Thus the figure of 20 cents seems a reasonable one.

Comparative costs are as follows:

Costs on the Basis of 150 Foot Rolls

Kodacolor Aero Reversal		Infrared Aerographic	
$270.20	Film	77.20	Film
27.02	Tax	7.72	Tax
11.80	Processing chemicals	30.00	Estimate for printing
309.02	Total	$114.92	Total

$\frac{\$309.02}{150 \text{ ft}}$ = $2.06 per foot $\frac{\$114.92}{150 \text{ ft.}}$ = $0.77 per foot

Figure 1. Transverse Section of a Continuous Strip Photograph on Kodacolor Aero Reversal Film. Second growth upland longleaf pine type of southern Alabama. Scale approximately 1/770 or 1" = 64'.