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LOW ALTITUDE STEREO-PHOTO TIMBER SAMPLING BY HELICOPTER

by

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Arnold W. Bolle
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G B Castle
Dean, Graduate School

June 11 1957
Date

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INTRODUCTION

The professional forester in the United States has become progressively more aware of the uses of aerial photographs. His attention has been directed toward the solution of general and specific problems, and many approaches have included the integration of aerial photographs as primary tools to attain satisfactory solutions. Essentially, aerial photographs have reached a high level of importance to the forester by saving his time and money through their use. This paper proposes a new method of obtaining aerial photographs and an approach to their use for forest inventories, which, the author hopes, will provide a solution to specific problems delaying their use for aerial inventories of our mountain forests.

Considerable attention has been directed toward the adaption of aerial photographs and interpretation techniques to derive timber inventories, thus reducing field work and cost. Much success has been achieved in the Eastern United States, Canada, and other areas of subdued topography. In the Rocky Mountains of the West, however, conclusive evidence supporting their use for aerial volume estimates is lacking. This lack of evidence is probably due to specific interpretation problems peculiar to the topographic extremes and the timber types of these regions.

The main factors delaying the application of aerial inventory techniques are: (1) the scale variation on a single photograph due to topography, (2) the inconsistent identification of species in mixed coniferous stands, and to a lesser extent, (3) the scale of available photographs and (4) the age of available photographs.

To combat these factors, this paper proposes a method of photographic sampling where large scale photographs are obtained for selected plots in a timber type. These stereo-paired pinpoints taken at a constant scale of 1:1000 would provide a basis for individual-tree measurements for volume estimates directly from the photographs. The large scale should allow for the ready identification of species. The photographs, taken specifically for an inventory, produce data relevant to the current stand condition. The altitude control, achieved by using a helicopter for the camera platform, should produce relatively constant scales, eliminating the ground control necessary for conventional aerial photographs.

RELATED LITERATURE

Aerial photography probably had its beginning in 1858. Prior to World War I, the progress of aerial photography as applied to forestry was slow. The progress of the forestry applications of aerial photography, since, has been developing at a continually increasing rate. The Germans were developing the fundamentals of aerial inventories by 1923, and the Canadians were producing aerial timber volume estimates by 1929. Foresters in the United States did not shift their interest to aerial inventories until the early 1940's. Since 1945, many investigators have obtained volume estimates from aerial photographs. At present, however, aerial photographs are normally used in combination with ground measurements for forest inventories.(18)

Few investigators have reported on the use of large-scale photographs for the measurement of tree variables. Mignery (11), Rogers (14), Losee (9), and Young (21) have indicated the results of studies involving large-scale aerial photographs.

Working with low altitude photographs taken by a Sonne strip camera, Mignery found that scale variation and image blurring were difficult to control. The scale variations resulted from relief in an area of relatively flat terrain. Image blurring was also caused by variable terrain elevations.

Mignery concluded that this type of photography is limited to flat terrain.

Also working with strip photography, Rogers states that the measurement accuracy at a photograph scale of 1:1200 was little better than the accuracy obtained from conventional scales. The effect of tree height, as related to scale, contributed to photo-interpretation errors.

Continuous strip photography was tested in view of possible photographic sampling applications.

Losee compared the measurement of tree heights and crown diameters on 1:1200 photographs with 1:7200 photographs. The 1:1200 photo scale was obtained with a 24 inch panning camera, and the larger scale with a precision mapping camera. He reported that the measurements were more reliable on the larger scale photographs. The study proposed to use the large scale as a photographic sampling method in conjunction with the 1:7200 photographs, eliminating the field work in aerial cruising.

Comparing photograph scales ranging from 1:3500 to 1:15,840, Young found that this reduction in scale reduced the accuracy of tree counts by 20%.

Continuous strip photography apparently, has no practical application as a photographic sampling technique in the Rocky Mountains. The panning camera would also be limited by terrain. The studies of Losee and Young, however, indicate that the accuracy of photographic measurements are increased by increasing the scale. Logically, the accuracy of species identification would also be increased.

THE PROBLEM

The problem, here, has been to devise a method of obtaining aerial photography, applied as an aerial sampling technique, which would feasibly eliminate the problems encountered in aerial inventories in the Rocky Mountain regions.

The problem of scale variation on a conventional photograph of mountain terrain is great. Some degree of scale control may be obtained when sufficiently accurate maps are available. Without these maps, however, ground control is often necessary to adequately determine the scale on various portions of the photograph. This is necessary for subsequently accurate estimates of tree variables and sample areas.

The second major problem is the identification of individual trees by species. In mixed stands, where the value between species is highly variable, it is imperative to estimate accurately the volume of sawtimber made up by each species, in order to have a true dollar value. In ground cruising, this is obtained directly by estimating the volumes on sample plots for individual trees by species. This problem is usually met by examining some sample plots on the ground when making an aerial inventory or cruise using conventional photographs. In mixed coniferous stands, species identification is so difficult that rather large ground samples may be necessary to establish volumes by species.

A third problem, the scale of photographs that are commonly available, may be less important, yet it is worth consideration. The common scales available to foresters are 1:15,840 to 1:20,000. The trend, however, appears to be toward larger scales, and photos having representative fractions in the vicinity of 1:10,000 to 1:12,000 are becoming more common. Yet these scales may seriously limit the accuracy of volume estimates by the individual tree method. Young (21) concludes that the common scale of 1:15,840 in the northeast restricts photo interpretation to the forest stand as a unit of measure.

Specifically, the problem of available photo scales limit the unit of measurement to the forest stand for two reasons. First, the difficulty or inability to measure individual trees and, second, the difficulty or inability to identify species in mixed coniferous stands, both of which are necessary for reliable value estimates. The problem is considered less important, because it is believed that, were the first two problems resolved satisfactorily, large scales would soon become available for inventory purposes.

Following this thought, the fourth problem --- the age of available photographs --- would be solved in a like manner. In many cases, the age of the available photographs prohibits their use for aerial cruises. The value of photographs five years old is doubtful, and photographs older than ten years are practically worthless for timber inventories.(17)

Again, ground reconnaissance and sampling is necessary to bring old photographs up to date. Reducing the field work, necessitates re-flying of the area, but the stands in question cannot always bear the cost of new and complete photo coverage.

A study of these problems led to the formation of an approach. Perhaps these problems could be eliminated or significantly reduced by a different method of obtaining aerial photographic samples, and perhaps some of the difficulties encountered by other investigators could be surmounted by modifying the methods for handling the photo-interpretation data. This, then, became the objective for furthur study.

THE PHOTOGRAPHIC SAMPLING SYSTEM

As the study proceeded, a number of questions arose concerning the components of an aerial photographic sampling method, which could be applied to aerial inventories of mountain forests. These questions or problems concerned (1) the type of photography, (2) the aircraft and camera equipment, (3) the camera mounting system, and (4) the relationship of photographic scale and parallax to limitations imposed by the equipment and mounting system. The following is a discussion of each of these components.

The Type of Photography

In this discussion and later discussions of the components, certain characteristics were believed to be desirable. The scale should be large enough to permit accurate species identification, and the control of scale should be good. In addition, the vertical exaggeration should be minimized, yet produce an approximate average height of two feet per one thousandth inch of differential parallax.

Logically, scale control and constant scales could be attained easier with vertical than with oblique photographs. Vertical photographs can be used as they are for the measurement of image dimensions. Normally, obliques would require rectification prior to the measurement of images.

The principle question, however, was that of individually exposed photographs or simultaneously exposed photographs. Vertical aerial photographs are usually taken by a single camera installed in an aircraft, and the exposure interval is timed to produce the desired overlap. Photographing a sample area at a low altitude would probably require two passes over the area by conventional methods. Regardless, the control of the camerabase (airbase) and parallax would be difficult. Colwell (5) considered the possibility of a twin-camera installation on a helicopter, but did not believe it to be feasible.

A twin-camera mounting system and simultaneously exposed photographs are desirable, in a problem of this nature, for three reasons. It has already been stated that one objective is to obtain constant scale photographs. These photographs would have no outstanding value unless the camerabase or absolute parallax were also controlled. Close control of the distance between the exposure stations is extremely difficult using a single camera installation. The principle reason for the desirability of simultaneous exposures, then, is the maintenance of a fixed distance between the cameras. This, in conjunction with a fixed altitude, would produce photographs having not only a common scale, but a common base-height ratio (or vertical exaggeration) as well.

A second reason for having twin-camera mounts is the saving of flying time. Normally at a low altitude, two passes would be expected for each stereo-pair. Twin cameras exposed at the same time over the objective would require only one pass to obtain the desired photographs.

A third reason, is the desire to control closely the position of a sample plot relative to the two principle points of the paired photographs and the scale of the two photographs. With two cameras fixed in position, the sample plot can always be placed at the same distance from the photo centers, and the scale of the paired photographs would be identical.

The Aircraft and Camera Equipment

The selection of suitable aircraft and cameras was a major concern in the development of this problem. Primarily, the success of future testing hinges upon the proper selection of this equipment./1 This development, perhaps, presents ideal equipment, and may differ from subsequent availability.

The Aircraft

Both fixed-wing and rotary-wing aircraft were considered in the initial phase of this study. The selection was based on the flight characteristics and capabilities which are most adaptable to constant scale photography at very low altitudes.

Continuous strip photography (10) is obtained using

/1 A brief outline of proposed testing is presented in the Appendix.

the Sonne camera. Usually, this camera is mounted in a relatively large and high-speed aircraft, and it is capable of sharp pictures at low altitudes, but the scale would not be constant and the images would not be altogether clear in rough terrain. Scale constancy and image clarity depend on the uniformity of the camera height above the ground, and high speed airplanes are not capable of contouring rough terrain precisely enough to maintain this uniformity.

The aerial panning camera (21) takes large scale photographs from a relatively high altitude utilizing a lens having a longer focal length. The panning camera would be subject to the same limitations as the strip camera in rough terrain, since the airplane cannot remain at a constant height above the ground.

An aircraft, capable of contouring mountain terrain safely at low altitudes, is needed for this type of photographic sampling. Comparing the light helicopter to the light airplane: The helicopter is more manueverable; It is safer for low flying; It can fly, out of ground effect, at lower airspeeds; It is safer at low airspeeds; and It can increase or decrease lift immediately without a corresponding change in airspeed. These features would permit the helicopter to be flown over an objective and, within reason, at a constant altitude. Therefore, the helicopter is believed to be the most adaptable aircraft for low-altitude photography, where a constant scale is desired in rough terrain.

In figure I, the helicopter is illustrated carrying two cameras mounted at right-angles to the longitudonal axis. The cameras are supported by a tubular boom, and the distance between the cameras is sixteen feet. The distance (eight feet on each side of the aircraft center) is believed to be near the maximum distance that can be utilized with the light helicopter. This sixteen feet becomes the camerabase, contributing to the absolute parallax.

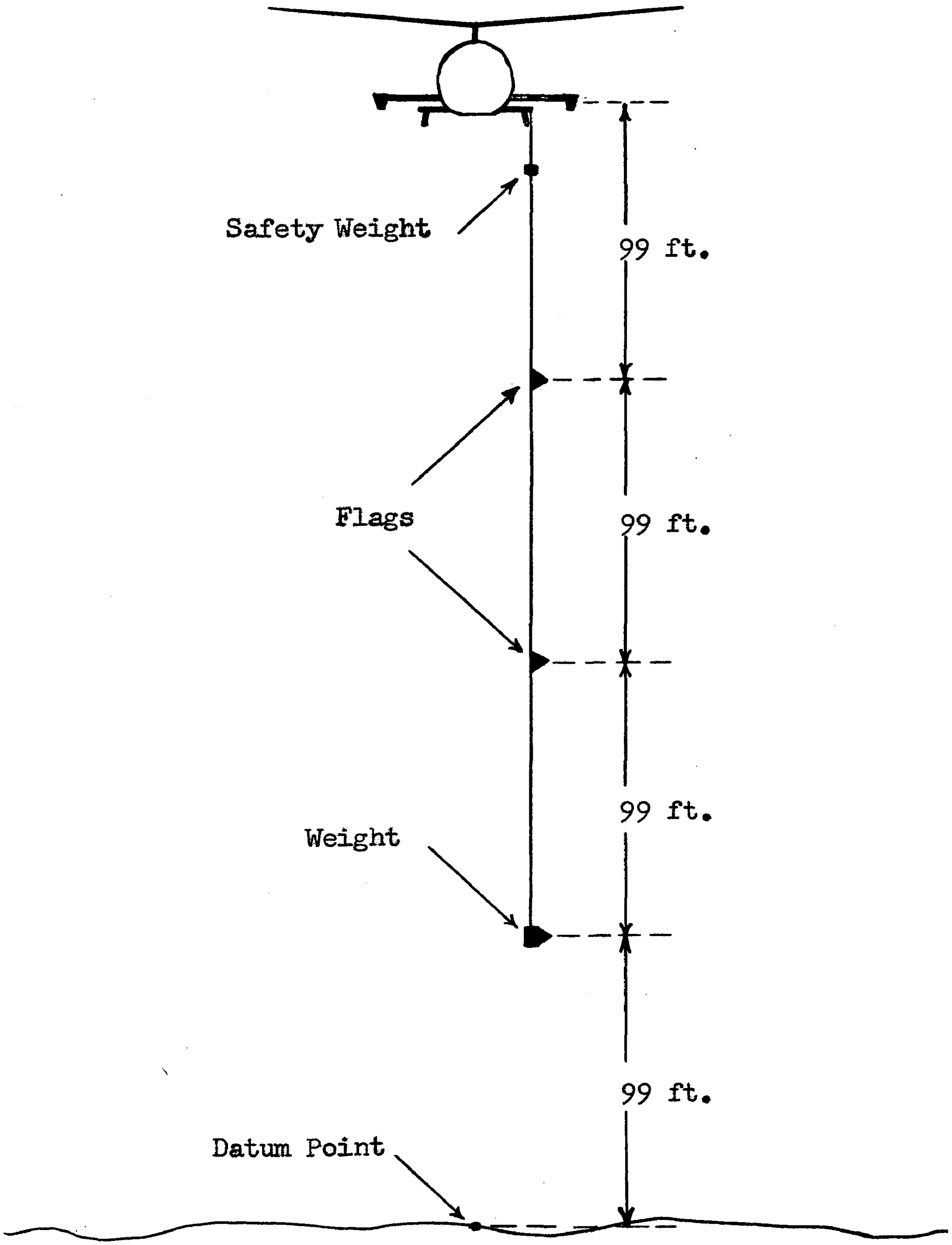
Type of Camera

Reasons for having a twin-camera mounting system and a helicopter for the camera platform have already been stated. Referring to figure I, the need for a camera capable of automatic operation and remote control is evident. Also, the camera should be very light in weight and have an economical format.

Of the aerial cameras available, the P-2 aerial strike camera (1) (19) (or similiar commercial models) has many desirable features. This camera is electrically operated (automatic or remote control), and weighs only eight pounds fully loaded with fifty feet of film. The camera has a 2.25 x 2.25 inch format, and it is equipped with a 76mm lens.

The strike camera's operational specifications (19) are well adapted to low altitude photography. The recycling is rapid, and the exposure speeds are fast (maximum 1/2000 of a second). The recycling rate (5 exposures per second) permits

Figure I - An Aid to Altitude Control



exposures at closer intervals than would be necessary. The maximum exposure time provides the flexibility necessary to eliminate image blurring due to helicopter vibration and apparent image movement. The format size is economical, yet it provides the photo space for relatively large plot sizes. The camera, however, would need to be modified for a 4.75 inch focal length lens, to provide the altitude and parallax characteristics proposed by this study./1

The Camera Mounting System

The camera mounting system, as illustrated diagramatically in figure II, affords a fixed camerabase of sixteen feet between the optical axes of the cameras. The cameras are supported by co-axial tubes and tubular supports attached to the landing skids of the helicopter. The co-axial tubes pass through the cabin of the helicopter.

A mounting system for large scale, low altitude photography should incorporate some method for reducing tip and tilt. This system utilizes an ordinary gyroscopic flight indicator, where the electrically driven gyroscope produces an artificial horizon. The vertical axes of the cameras, control stick, and flight indicator are parallel. When the flight

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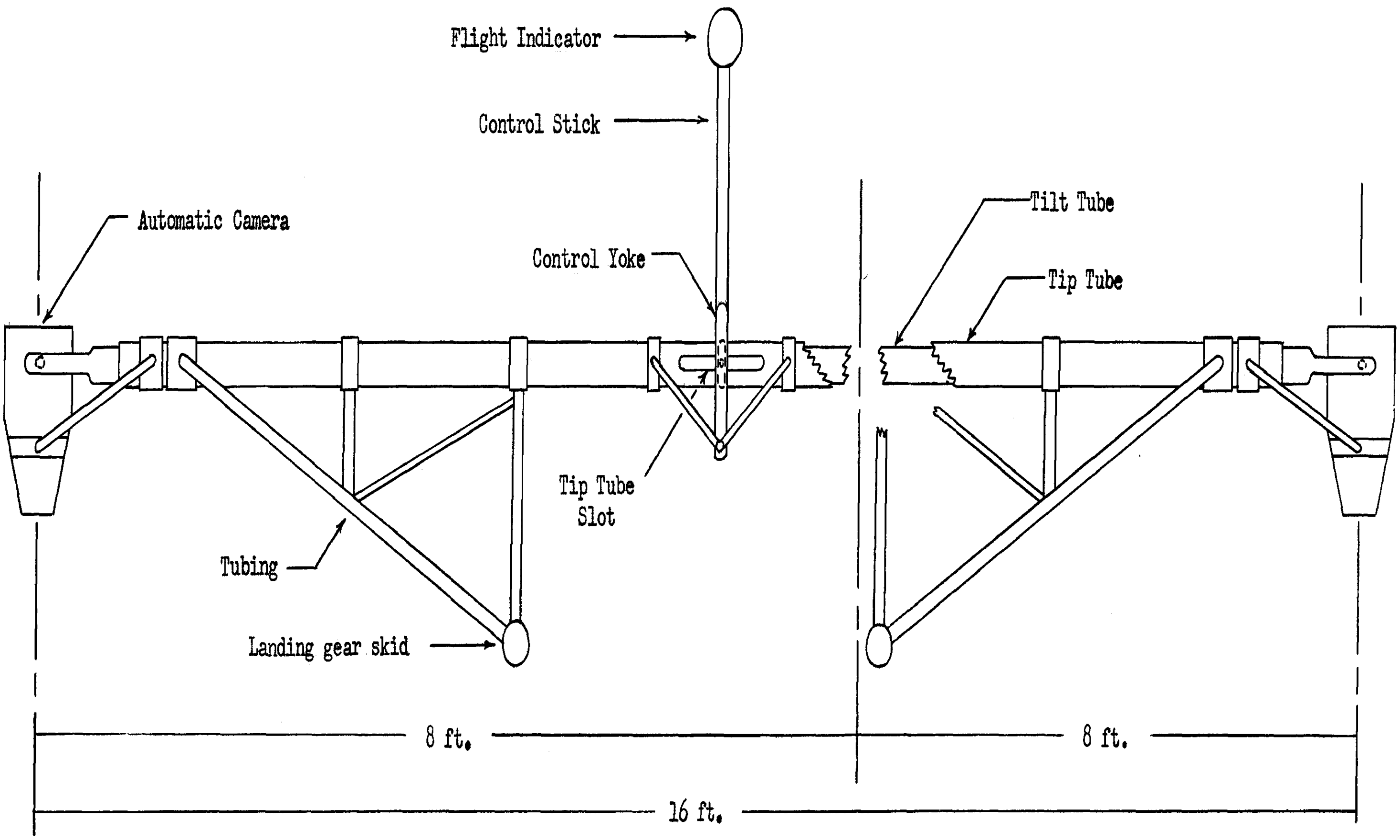
/1 This discussion does not intend to present the aerial strike camera as the only camera suitable for low altitude photography, but does intend to show that the camera would not be a limiting factor. The K-24 camera (10) probably could be used. It is heavier and has a 5 x 5 inch format.

Flight II - The Camera Mounting System
(A Front View)



indicator is referenced to the true horizontal, then, any change in the attitude of the indicator and cameras from the reference is shown.

The control stick is attached rigidly to the outer tube (tip tube). A movement of the control stick fore and aft rotates the co-axial tubes and the cameras in a fore and aft direction. The control stick is attached to the inner tube (tilt tube) by studs on the control yoke which pass through a slot in the outer tube and engage holes in the tilt tube. A movement of the control stick laterally, left or right, causes the tilt tube to slide left or right within the outer tube. This tilts the cameras in a lateral direction through the same arc as the control stick, since, the radii of rotation for the cameras and the control stick are the same. The lateral and longitudinal movements of the control stick may take place simultaneously, giving 360 degrees control over the direction of the optical axes of the cameras. As illustrated, the system provides control movements through arcs of approximately 30 degrees.

In operation, the cameras, mounted on the helicopter, would be plumbed vertically prior to a flight. With the gyroscope operating, the flight indicator would be adjusted to the horizontal reference line. In flight then, any change in the attitude of the helicopter from the horizontal will rotate the cameras from the true vertical. The amount and direction of this change can be viewed on the flight indicator, and the cameraman can move the control stick in the direction necessary to align the indicator horizontally. In this manner, the optical axes of the cameras are maintained nearly vertical at the instant of exposure independent of the attitude of the helicopter. The cameraman, in a sense, is flying the cameras in level flight.

The Relationship of Photographic Scale and Parallax to the Limitations of the Aircraft and Mounting System

The relationship of scale, as determined by the lens focal length and the flying height, to stereoscopic parallax requires consideration to obtain desired photogrammetric characteristics. In this development, the design of the photographic mission must also consider equipment limitations.

In an analysis of the characteristics of stereoscopic parallax by Colwell (4):

> "Parallax is defined as the apparent displacement of the position of a body with respect to a reference point or system caused by a shift in the point of observation. The basic parallax formula takes the following form:
>
> $$h \quad - \quad \frac{H \text{ x } dP}{P \not- dP} \qquad (1)$$
>
> Transposing: $$dP \quad - \quad \frac{P \text{ x } h}{H - h} \qquad (2)$$

When the parallax equation is rewritten in this second form, the following factors are seen to govern the stereoscopic parallax characteristics of photographic images and in the fashion indicated:

(1) P, (the absolute parallax of the base of the object photographed) appears only in the numerator of equation (2). Hence the magnitude of dP is directly proportional to that of P.

(2) H, (the height of the camera lens above the base of the object) appears only in the denominator of equation (2). Hence the magnitude of dP is inversely proportional to the magnitude of H.

(3) h, (the height of the object) appears in both the numerator and the denominator of equation (2). However, its effect in the numerator, as a multiplicand, far exceeds its effect in denominator, as a subtrahend, in conventional aerial photography. Accordingly, for all practical purposes, the magnitude of dP is directly proportional to the magnitude of h./1

It will be noted that neither camera focal length nor photographic scale is listed in the above analysis as a factor directly affecting stereoscopic parallax. However, the indirect effects of focal length and scale, through their influence on one or more of the factors just listed must not be overlooked. Since photographic scale, (S), is equal to camera focal length, (f), divided by the altitude of the camera above the object photographed, (H-h), it is obvious from direct substitution in equation (2) that

$$dP - \frac{P \times h \times S}{f} \qquad (3)$$

From equation (3) it is at once obvious that dP is directly proportional to S and inversely proportional to f".

It is evident, then, that the relationship of altitude, focal length, and camerabase to scale and stereoscopic parallax is governed by the design of the photographic system. The design of any photographic system, or the planning for any

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/1 The effect of the object height on differential parallax can be demonstrated by a parallax graph constructed for any given photographic conditions. (2) (12)

photographic mission, incorporates a desired relationship between the above variables, based upon a desire for specific photographic characteristics. In other words, the system may be designed to produce a large or a small scale, and to exaggerate or minimize topographic relief (or object height) in the stereo-model.

Essentially, if we control the height of the exposure station above the ground, the focal length of the lens, and the distance between the exposure stations, we have positive control over the scale and parallax characteristics. This control, of course, is dependent on the photographic equipment and transport medium.

The photographic equipment, as it pertains to cameras, probably cannot be considered as a limiting factor, since several types of automatic, light-weight cameras exist. In any event, future testing of this system would probably utilize the best available cameras and lenses. The camera mounting system and the helicopter, however, do impose some limitations on the photographic characteristics.

The twin-camera mount, as previously described, limits the distance between the exposure stations. The overlap between a normal stereo-pair of aerial photographs is approximately sixty percent. Whereas, the overlap utilizing a sixteen foot distance between the cameras and a R.F. of 1:1000 produces an overlap of 91% on a 2.25 inch format or 96% on a 5 x 5 inch film. Nevertheless, a comparatively short camerabase and large overlap cannot be considered as a detriment in large scale photography, since a normal overlap obtained from a low altitude might produce excessive differential parallax. In this case, the photo-interpreter would be unable to fuze the total image height in the stereo-model. For this study, then, the maximum feasible camerabase is fixed, and the focal length and flying height are adjusted to produce the desired relationship.

Consideration for the flying safety of the helicopter also limits the design of the photogrammetric characteristics. Normally, helicopter pilots prefer to fly at 400 to 500 feet above the ground. This height permits them to execute a power-off landing in an emergency. Related to this, constant scales can be achieved only by a constant height above the ground. Maintaining a constant height depends on the pilots judgement of depth. Logically, the accuracy of distance estimation by eye decreases as the height increases. Therefore, it is important to keep the flying height as low as possible yet safe and practical.

The scale and stereoscopic parallax characteristics as proposed by this study were developed, by trial and error within the above limitations. These characteristics would produce a negative value for the vertical exaggeration (common to conventional aerial photography) (20), yet the average tree height per one-thousandth inch of differential parallax would be less than two feet. Theoretically, this would allow photo-interpreters, trained with the parallax wedge, to measure tree heights within a plus or minus two feet.

The proposed photogrammetric relationships provide an R.F. of 1:1000, a focal length of 4.75 inches, a camerabase of 16 feet, and a flying height of 396 feet. These values should not be considered necessarily ideal. However, they appear to provide a suitable basis for photographic measurements.

The relatively large scale was selected, within the limitations, primarily to facilitate species identification. An optimum scale for identification purposes is not known, but it is reasonable to expect a substantial increase in the accuracy of identifying species at a large scale. In coniferous forests, the structure of individual trees probably would be an additional criterion.

The camerabase produces an absolute parallax of 0.192 inches at the datum plane. From the basic parallax formula, a 100 foot tree height above datum produces .065 inches of parallax difference, and the parallax factor is 1.54. This factor decreases for taller trees and increases for shorter trees. Figure III, shows the relationship of tree height to differential parallax values. Here, differential parallax values are plotted on the abscissa and tree heights on the ordinate. This graph converts the measurement of parallax differences to tree heights above the datum plane in feet.

For linear measurements, such as plot radii and crown diameters, one inch on the photograph is equal to 83.33 feet on the ground. The graphical conversion of crown diameters measured on the photos to crown diameters in feet is shown by figure IV, where crown diameter measurements in inches are plotted on the abscissa and the corresponding value in feet is obtained on the ordinate. A standard one-fifth acre plot/1 has a radius measurement of 0.632 inches on the photographs.

/1 Rogers (15) proposes the one-fifth acre plot as a standard for photo-interpretation studies.

APPLICATION

The proposed application for this method of obtaining photographic samples of timber stands is essentially the same as proposed by Losee (9). Conventional aerial photography would be used to delineate forest types and stand classifications. Area determinations would be obtained for the stands as they are marked on the available photography. A sampling design would be determined utilizing the advantages of stand stratification, and the location of the sample plots would be marked on the photographs. Up to this point, the system is identical, individual variations excepted, to any photo-controlled ground cruise. Hereon, the system differs principally in the amount of ground work associated with forest inventories. Normally, the checking of type delineations and stand classifications occur prior to, in the form of a ground reconnaissance, or concurrently with the measurement of sample plots on the ground. By the stereo-photo timber sampling method, the photo-interpretation of types and stands would be checked from the air (6) (8) just prior to flying the areas for photo-samples. Adjustments would be recorded on the conventional photographs in the air by the cameraman-observer. Then, the sample plots would be photographed at a large scale in the manner described in the following paragraphs. The operation of a helicopter is costly. Therefore, it is suggested that the ferry time from the base of operations to the forest area and return be limited to a single round trip. Ordinarily this can be done by trucking fuel and supplies to a location within a reasonable flying time from the work area. In cases where the flying may extend over several days, food and camping equipment should be available at the fuel dump.

Photographing the Sample Plots

The key to successful photography, having a relatively constant scale between photographs, rests on the ability to control the flying height of the cameras above the datum plane. A helicopter similar to the Bell model 47 G-2 (3) presents the minimum airspeed and manueverability characteristics required to obtain clear photographs from a given flying height. The judgement of the height above a point on the datum plane, however, depends on the pilot's ability to estimate vertical distance. Since the pilot can convert his altitude sensings into helicopter control movements immediately, the responsibility for determining the correct altitude and signalling for the exposures is left to him.

Referring to figure I, this illustration shows a very simple means to aid the pilot in estimating his height above the datum point. In general, professional helicopter pilots become adept at judging distances to the ground under 500 feet. A light, weighted line payed out in the air with flags attached at known distances along the line aids the pilot in judging his datum altitude. A light nylon or plastic fishing line with sufficient strength to support a ten pound weight serves this purpose. As an example, flags could be attached at intervals of 99 feet below the axis of the camera base. The pilot, then, would need to judge only one 99 foot interval beyond the end of the line to the ground, using the flagged line for perspective. This length of line should work when the general stand height is under 100 feet. Other interval combinations could be worked out for taller stands.

The use of a very light, small diameter line, with a relatively heavy weight, eliminates much of the trail that would result from the air resistance on a heavier line. Also, if the line is snagged, it will break without effecting the helicopter's flight. An additional weight of perhaps two pounds is attached fifteen feet below the helicopter as a safety device. In case the line snags and breaks at a point below this weight, the line will be prevented from flying up and fouling the tail rotor. If the line breaks above the safety weight, it is too short to foul in the tail rotor. Oscillations are not expected to present a problem./1

With the helicopter equipped in the manner illustrated in figure I and with the cameras and flight indicator referenced to horizontal, the photography team is ready to photograph the sample plots. Some emphasis should be placed on

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/1 The line is attached near the center of gravity, and this point on the aircraft does not change position rapidly, under normal flight conditions.

the complete co-operation necessary between the pilot and the cameraman in order to complete the photo mission successfully. The pilot and the cameraman should become familiar with the area during the type checking phase. While the cameraman is checking the typing, the pilot should orient himself with the area and the general location of the sample plots. In addition, he should decide on the safest and best direction of flight for approaching the plots. Normally, this would mean flying, as much as possible, into the wind and parallel to the slope.

The photographic sampling is initiated by the pilot, who brings the helicopter over the first plot at the predetermined flying height and at a minimum airspeed./1 When the helicopter is over the plot, the pilot signals the cameraman, who has been keeping the cameras directed vertically, to trip the shutters, which are synchronized electronically. The helicopter would proceed to each successive plot by the most direct route, until the selected number of plots had been photographed. Refueling of the helicopter and reloading of the cameras may interrupt the procedure. These interruptions, however, could be minimized by proper planning.

Probably, the photographing of the exact location of

/1 Under moderate wind conditions, the actual ground speed may be as low as 0 to 15 m.p.h., when the helicopter is flying into the wind at 25 to 30 m.p.h/

the pre-selected plots is not too important. Rather, the plot locations on the conventional photography should be used to guide the distribution of the photographic samples. Also, good altitude control should not be expected in the initial testing. However, as the pilot gains experience with this photography, it is hoped that he can judge the flying height within a plus or minus 20 feet.

Handling the Photo-measurement Data

After the photographic sampling is complete, the film processed, and printed photographs obtained, the interpretation of the sample plots begins. The identification of species, of course, would depend on the interpreter's judgement. The measurement of tree heights can be accomplished with a parallax measuring instrument, such as the parallax wedge. Crown diameters and plot areas would be measured by constructing the common types of transparent overlays to provide the latitude of measurement necessary at this large scale. The primary difference in the handling of the photo-measurements on these photos from conventional photographs is to treat the tree height as topographic height, similar to methods used in topographic mapping which circumvent the calculation of differential parallax for control points. (12) The methods of handling the data, in a general form, are outlined in the following paragraphs.

The midpoint of a one-fifth acre plot, having a radius of 0.632 inches, is placed at the midpoint between the photo centers, as they are viewed stereoscopically. This point is also the datum point, which lies on the datum plane. The scale at this point is 1:1000 (assuming the flying height to be 396 feet), and the absolute parallax of all points on the datum plane is 0.192 inches, computed from the formula $P - \frac{Bf}{H}$. The differential parallax, produced by the height of a tree whose base occurs on the datum plane, can be measured by the parallax wedge or other instruments. When converting parallax measurements of tree height on conventional photographs, a parallax factor is usually computed which assumes the differential parallax to vary as a straight line with tree height. The relationship between parallax difference and tree height, however, is curvi-linear rather than linear, and the linear assumption would produce rather large errors in tree height using large scale photographs. Therefore, a parallax graph (figure III) is used to convert differential parallax to tree height. To illustrate the use of the graph, an assumed parallax measurement of 0.052 inches indicates a tree height of 84 feet. Computing the tree height from the formula ($h - \frac{H \times dP}{P + dP}$) gives 84.3 feet.[1] Also, this height represents the actual tree height rather than visible height due to limited resolution on conventional photographs.

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[1] The original graphs were prepared on graph paper having 20 graduations per inch.

Figure III - The Conversion of Differential Parallax to Tree Height

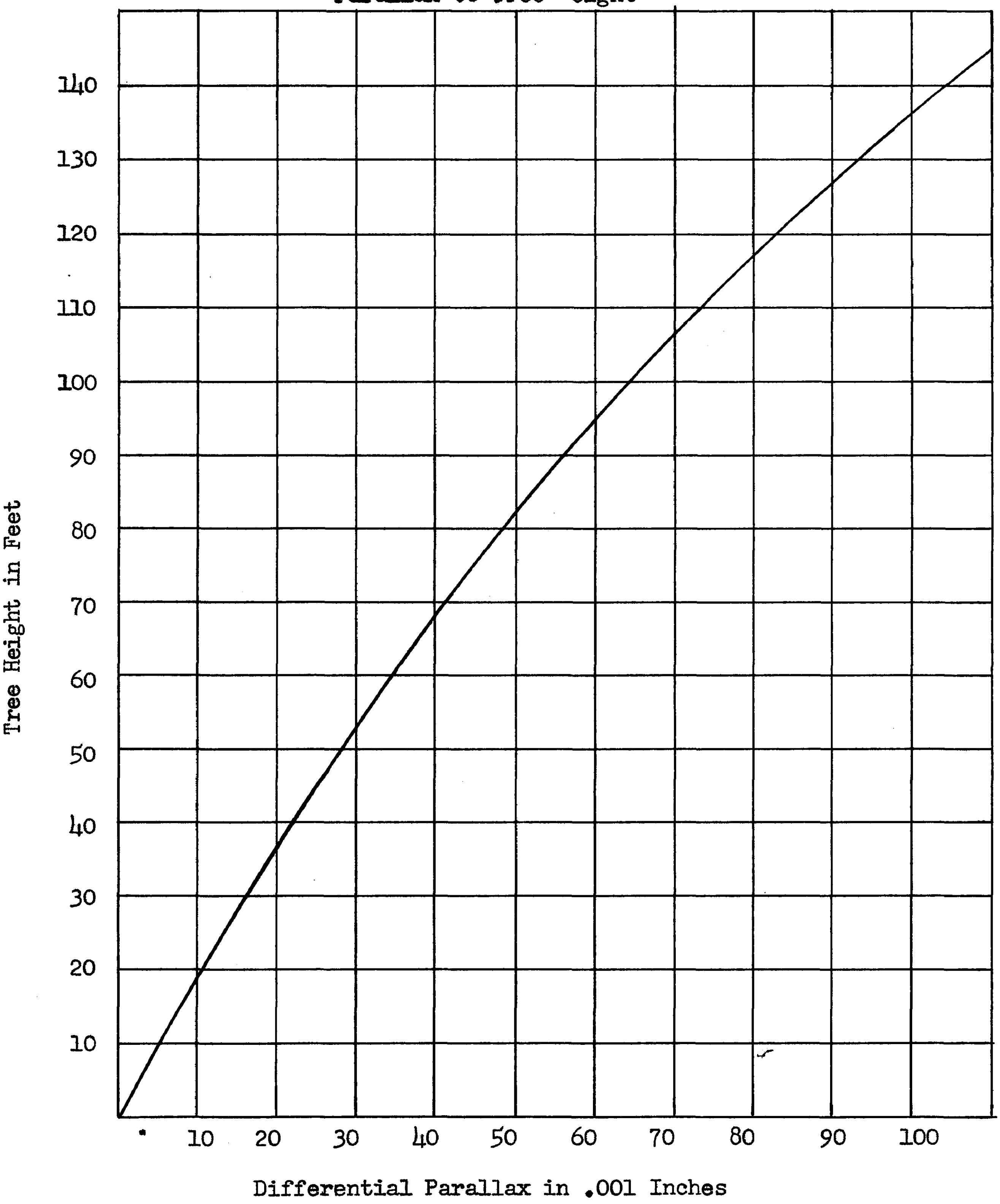


Figure IV - The Conversion of Crown Diameters in Inches to Feet

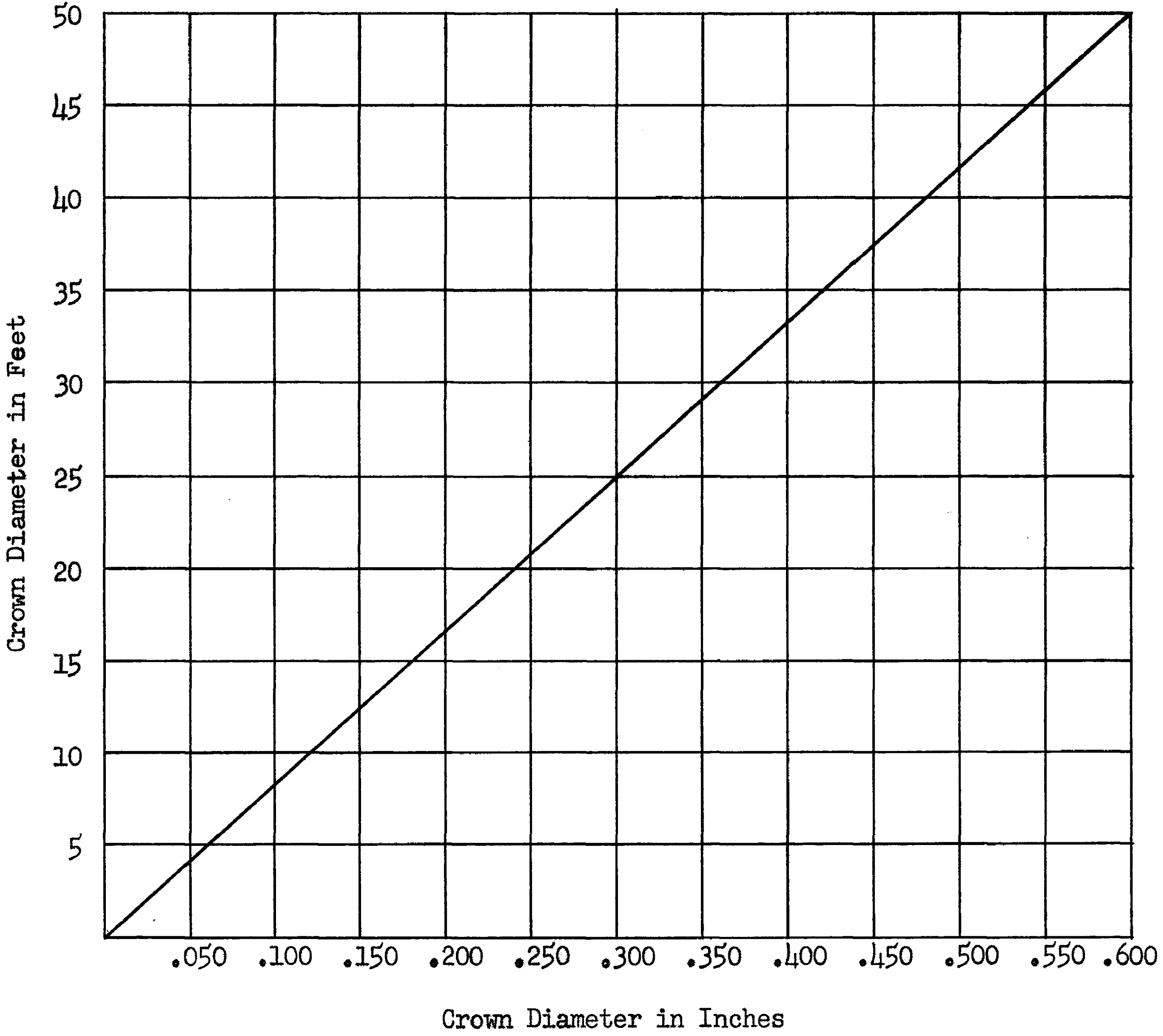


Figure V - The Relationship of Tree Height Above Datum to Photo Scale

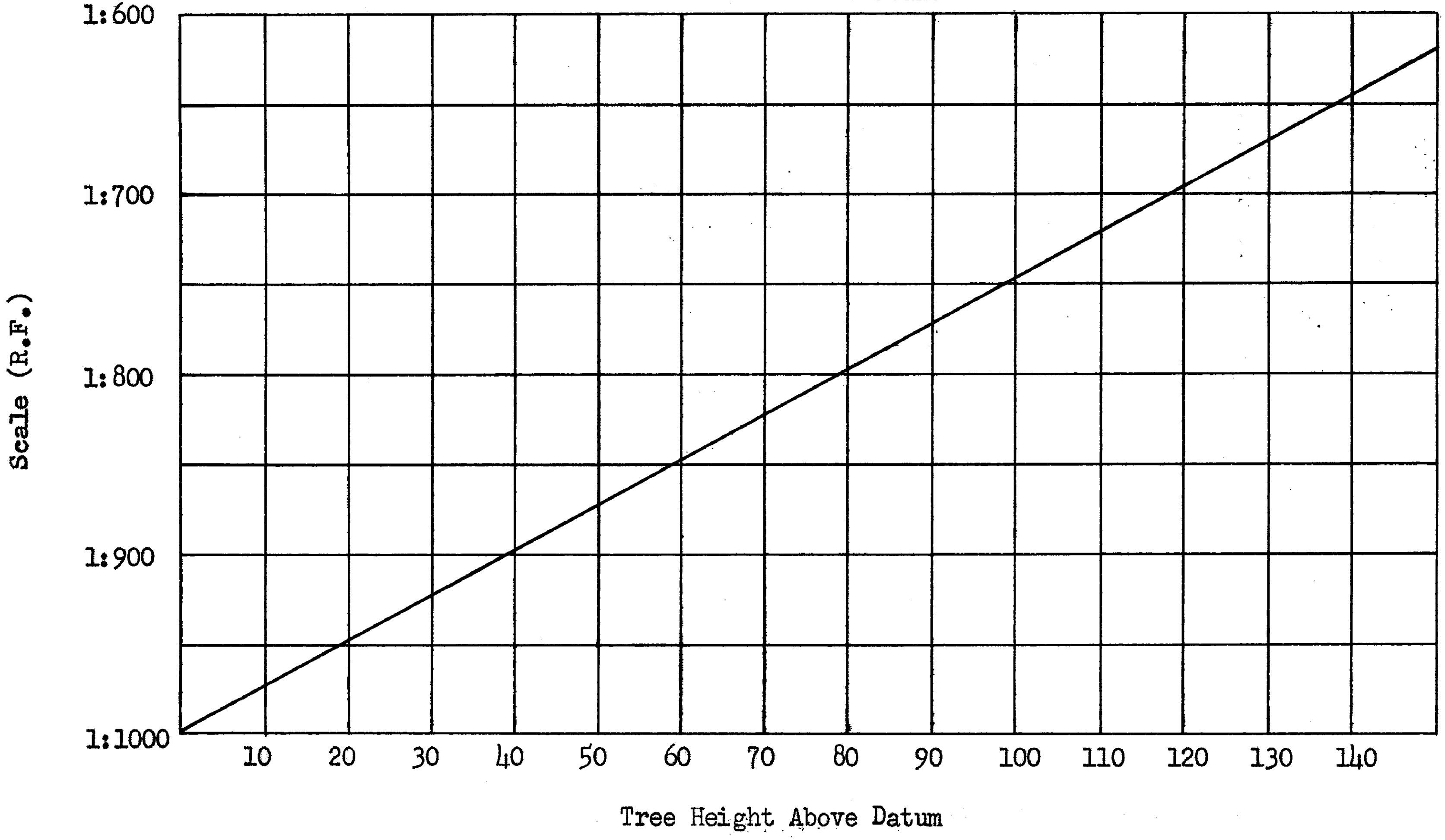
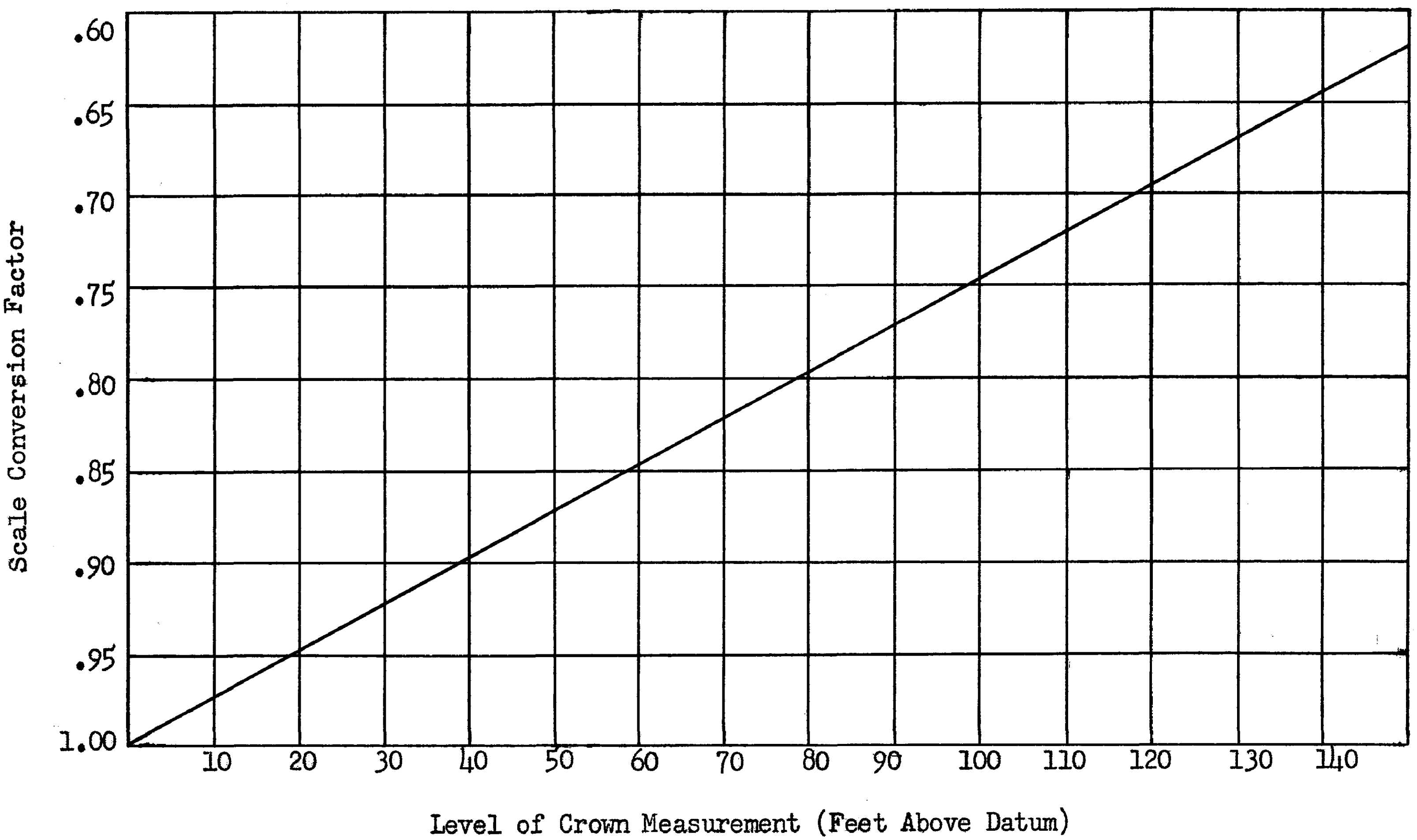


Figure VI - Scale Conversion Factors for Crown Diameter Estimates



Crown diameter measurements must also be approached from a modified view on large scale photographs. The term "constant scale" perhaps is a misnomer, in that the scale of individual photographs would be constant only at a given point, such as the plot center, or on a given plane, such as the datum plane. The scale of all photographs would be approximately the same at the plot center. Considerable scale variation occurs on an individual, large scale photograph between points above, below, and on the datum plane. Scale varies greatly on these photographs, taken from a low altitude, however, this need not be a disadvantage so long as it is accounted for. Figure IV, shows the relationship of photo-measurements to ground measurements, and converts crown diameter measurements in inches to feet at a scale of 1:1000. This, however, is not sufficient, since crown diameters are measured at some height above rather than at the tree base. Figure V shows the relationship of scale to tree height above the datum plane. An estimate of the height of measurement, by parallax measurement or ocular judgement, is necessary along with conversion factors to convert crown diameters at 1:1000 to true crown diameters at the actual scale for the height of measurement. Figure VI gives the conversion factor at the height of the crown diameter measurement above the datum plane. An assumed crown diameter measurement of 0.343 inches gives a crown diameter of 28.5 feet from figure IV. If it is furthur assumed that this measurement occurred at 50 feet above the base of the tree, then a conversion factor of 0.874, from figure VI, is used to obtain the actual crown diameter of (28.5 x .874) 24.9 feet. Converting 0.343 inches by the actual scale gives 25 feet.

The photo-interpretation data, obtained from the sample photography, would be used to estimate sawtimber volumes for each plot, applying the data to aerial volume tables constructed for each species or group of species. The plot volumes would then be used to estimate the total volume for the stand in which the plots were taken.

Species identification is highly qualitative, in that, recognition depends on pictorial qualities in addition to the interpreter's judgement. The general assumption is that the recognition of species would increase with an increase in scale. Losee (9) indicates that species could be recognized by the tree crowns better than by tonal contrasts at a scale of 1:1200. Rogers (13) assumes that optimum recognition would occur at some scale, and indicates the need for research using both large and small scale photographs.

Rogers (15) points out the difficulties in comparing the results of research relative to the accuracy of tree measurements and volume estimates at various scales. In general, studies have not been comparable, but those of Losee and Young bear out the assumption that photo-measurements and volume estimates are more accurate at larger scales. This paper does not argue the relative merits of the individual-tree approach or the stand approach to volume estimates. However, the author believes the individual-tree method, as approached by Fernette (7), has definite applications in the Rocky Mountains, when species recognition and photo-measurements are reliable. The individual-tree method, used with large-scale photographic sampling, presents a feasible means for estimating timber volumes by species, thereby affording a basis for value estimates. The application of this method with conventional photography has been questioned due to the inaccuracies of photo-measurements. Sammi (16) reports that tree heights were estimated to an accuracy of plus or minus 24 percent, individually.

Introduced Errors

Undoubtedly some variation in the flying height of the helicopter above the datum point would occur. These variations, however, would probably be compensating. Assuming that the flying height varies from 396 feet by a plus or minus 20 feet, then the extremes of scale at the ground level would be from 1:1050 to 1:950. A tree 100 feet high with its base at a scale of 1:1050 produces 0.058 inches of differential parallax. From the graph of parallax differences, this indicates a tree height of 91.7 feet, or an error of a minus 8.3%. At a scale of 1:950, a 100 foot height produces a differential parallax of 0.073 inches. The graph indicates a tree height of 109.3 feet for this parallax difference, or an error of a plus 9.3%. Theoretically, a 100 foot tree would be measured within an accuracy of a plus or minus 10% under this assumption.

Since linear measurements vary directly with the scale, errors in estimating crown diameters due to variations in flying height would be expected to be largely compensating. Assuming that a 25 foot crown width occurs midway along a 100 foot tree, the measurement level would occur at 50 feet above the base of the tree, and the crown diameter would be correctly estimated using figures IV and VI when the scale at the base of the tree is 1:1000. On the other hand, errors in estimating crown diameters result from the use of the graphs when the flying height varies. These errors are due to misjudging the level of measurement relative to the datum scale of 1:1000. If the above tree's base occured at a scale of 1:1050, the crown diameter would be estimated at 23.72 feet. If the tree's base occurred at a scale of 1:950, the crown would be estimated at 26.12 feet. This indicates that a crown diameter of 25 feet would be estimated within a plus or minus two feet, under the assumed variations in flying height.

Circular plot areas vary with the square of the radius. A one-fifth acre plot has a radius of 0.632 inches at a scale of 1:1000. A plot template constructed for the datum scale would enclose an area of 0.2208 acres at an R.F. of 1:1050. This is an error of a plus 10.4%. At an R.F. of 1:950, the plot area would be 0.1804 acres, or an error of a minus 9.8%. Again variations in flying height would cause an error in the vicinity of a plus or minus 10%.

The use of a plot template assumes that the plot surface occurs on the datum plane. In mountainous regions, this would be the exception rather than rule, since the plots would normally fall on a slope. The center of a circular plot is considered as the datum point lying on the datum plane. The effect of errors resulting from gound slope would be largely compensating, since half of the plot is below datum and half is above datum. Systematic errors, similar to those resulting from variations in flying height, would occur. Since the area of a plot varies as the square of the radius, a positive error in area measurement would be expected. Likewise, a positive error in height estimates would result from the slope of the sample plots.

The systematic errors that would probably appear in the photo-measurement data should be carefully analysed using photographs of the sample plots. Apparently, these errors would result in positive accumulations, and a thorough analysis should develop correction factors which could be applied to the data.

CONCLUSION

Admittedly, the foregoing discussion is basically hypothetical. It is doubtful whether all of the problems involved in low-altitude, stereo-photo timber sampling could be foreseen by one person. Nevertheless, this method of photographic sampling presents a feasible approach to the problems delaying the application of aerial inventory techniques in the Rocky Mountains. The mounting of twin-cameras, controllable for tip and tilt, on a helicopter, is a practical possibility. The stereo-paired photographs obtained with this equipment can provide a basis for the accurate measurement of image dimensions. The reliability of measurements and the consistency of species identification would probably increase substantially over that obtained from conventional photography. The application of this photographic sampling method, complimentary to full photo-coverage, would reduce the problems of available photo-scale and age. Stereo-photo timber sampling by helicopter is definitely believed to be worth the expenditure of effort and money for furthur investigation.

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APPENDIX

An Outline For Future Testing

Since an investigation of the actual capabilities of stereoscopic helicopter photography would require the expenditure of substantial research funds, the testing is believed to be more economical when divided into phases. Conducting the investigation by phases would also increase the probability of success. The following outlines briefly each phase of the proposed future testing.

Phase I, Ground Testing

a) Simulate the photographic conditions pertaining to flying height, lens focal length, and camera-base on the ground.

b) Photograph prepared targets of a known size placed at varying distances from the cameras. Construct the targets to demonstrate minimum resolution.

c) Interpret the stereo-pairs obtaining photo-measurements of the image dimensions of the targets, estimating their actual size. Measure parallax differences between the target planes and estimate these distances.

d) Compare photo-estimates to actual measurements.

e) Analyse scale variations.

f) Make necessary modifications in the photographic conditions.

Phase II, Construction and Testing of the Camera Mounting System

a) Obtain adaptable camera equipment and a flight indicator.

b) Construct prototype of camera mounting system.

c) Mount the system on a helicopter and perform authorized flight tests.

d) Photograph open terrain both sloping and level. Photograph targets and/or objects of known dimensions, using several shutter speeds.

e) Interpret the photographs.

f) Compare the effects of variations in flying height to scale constancy.

g) Analyse the effects of slope on the scale.

h) Determine the variability of the optical axis of the cameras from the true vertical.

i) Modify as necessary.

Phase III, Testing the Method for Timber Sampling

a) Photograph pre-selected plot areas representing variations in stand size, density, and species composition.

b) Estimate tree variables from photo-measurements for the sample plots.

c) Measure the tree variables on the ground.

d) Compare photo-estimates to ground estimates.

e) Modify as necessary.

Phase IV, Testing Volume Estimates

a) Gather data from a selected area and construct local aerial volume tables.

b) Classify stands on the available photography.

c) Determine the sample plot distribution.

d) Fly the area checking stand classifications and photographing the sample plots.

e) Interpret the photographs.

f) Apply photographic sampling data to volume tables to obtain volume estimates.

g) Compare aerial volume estimates to ground estimates of volume and/or the volume of timber cuts from the area.

h) Compare the costs of photographic sampling to ground sampling.