Effect of Photographic Scale on Precision of Individual Tree-Height Measurement

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ABSTRACT: *An experiment into the effect of photographic scale on the precision of tree-height measurement is described. The same 14 trees were measured twice by each of two operators, with both the parallax wedge and a parallax bar, on photographs at 1:20,000, 1:15,000, 1:10,000, and 1:5,000. The resulting statistical analysis indicated that errors in tree-height measurement are not associated with photographic scale, but are associated with some undetermined tree characteristic, probably crown shape or tree size, and with the individual operators. In addition, the evidence indicates that both instruments yield essentially equally precise results.*

THE generally accepted rule, relating to the effect of photographic scale on the precision of individual tree-height measurements made with parallax instruments, is that the magnitude of the residual random error of differential parallax is directly proportional to the least reading on the instrument, or to the minimum amount of differential parallax that can be detected by the operator. Thus, using the conventional parallax formula and assuming (1) a given instrumental least reading or a limit of differential parallax perception, (2) a given stereobase, and (3) a given focal length, the expected precision of measurement for any scale can be easily computed. When this is done the theoretical effect of scale becomes evident.

Because of the very strong theoretical evidence of the positive effect of scale on the precision of tree-height measurement, little work has been done to confirm or refute the theory. In 1945 (7), and again in 1948 (8), Spurr stated that tests at the Harvard Forest supported the theoretical values. These results have been widely accepted as final. In 1951, however, the Swedish Committee on Forest Photogrammetry (Kommittén för Skoglig Fotogrammetri) (4), published a report on an extensive series of tests in which the values for the residual random errors did not follow the theoretical pattern. This confusion of results led to the initiation of an independent study of the problem by the Forestry Department of the Agricultural Experiment Station, Alabama Polytechnic Institute.

The objectives of this study were: (1) to establish by experiment the precision that could be expected when the heights of individual trees were measured with parallax instruments on vertical aerial photographs of varying scales, and (2) to establish the relative precision of height measurement using the parallax wedge and the parallax bar.

PUBLICATIONS COMMITTEE NOTE: Although the subject and information contained in this paper are very similar to what was published in the December 1957 issue of PHOTOGRAMMETRIC ENGINEERING, it is the opinion of the Publications Committee that this paper too should be published. In many respects it differs from, expands and supplements the paper by Robert Pope. The separate investigations of the same subject at two widely separated points and by different personnel are always of interest. Further, the great similarity of results obtained, strengthen the opinions expressed in each paper.

METHOD OF STUDY

PHOTOGRAPHS USED

The Tennessee Valley Authority generously donated the use of the photographs used in the effect of scale study described by Bateson (1). These photographs were taken during August, 1949.

TABLE 1

SPECIES AND TOTAL HEIGHTS OF THE SAMPLE TREES USED IN THE TREE HEIGHT MEASUREMENT STUDY. DATA FROM EASTERN TENNESSEE. 1949

Tree No.	*Species*	*Total Height*	*Tree No.*	*Species*	*Total Height*
		Feet			*Feet*
1	Sweetgum	44	8	Pecan	67
2	Elm	56	9	Virginia Pine	16
3	Yellow-poplar	55	10	Sycamore	52
4	Yellow-poplar	67	11	Yellow-poplar	70
5	Red maple	41	12	Red oak	64
6	Sugar maple	48	13	White oak	31
7	White oak	60	14	Red cedar	42

Four scales were available: 1:5,000; 1:10,000; 1:15,000; and 1:20,000. All four flights were made over the same strip centerline. This strip ran northward, along the meridian 84°16′15″ West Longitude, from the Appalachia power station on the Hiwassee River to the vicinity of Sweetwater, Tennessee. Panchromatic film was used, with a Wratten A25 (medium red) filter, in a Fairchild F-56 camera equipped with an 8.25-inch focal length lens (3). The format size was 6.66×6.92 inches, with the longer dimension along the direction of flight.

THE BASIC TREE DATA

The total heights of 14 trees were measured at the time of photography by T.V.A. personnel using Abney levels. With the exception of one tree, which could not be viewed stereoscopically at one scale, all of these trees were visible on all four sets of photographs. In addition to the height measurements, the T.V.A. personnel also measured the lengths of check lines adjacent to each of the afore-mentioned trees in order to provide bases for computing true photographic scales. These data were used in the T.V.A. study for instrument calibration purposes. In the present study they provided the known parameters against which the photo-measured values were compared.

An attempt was made to obtain additional sample trees. This attempt, however, was unsuccessful. Five growing seasons had elapsed since the time of photography, making it impossible to obtain measurements comparable to those that would be obtained from the photographs.

The 14 sample or index trees were invariably open-grown but included a rather wide range in species and dimensions. These data are listed in Table 1.

THE STATISTICAL DESIGN*

Two operators measured the height of each of the 14 trees on each of the four sets of photographs. This sequence was carried out twice with the parallax wedge† and twice with the parallax bar.‡ Three operators were actually used. One completed the work on both instruments, while each of the remaining two worked on only one instrument.

MEASUREMENT PROCEDURES

The measurement program followed a definite pattern of sequence. Each operator first measured the 14 trees on the 1:20,000, then on the 1:15,000, next the 1:10,000, and, finally, on the 1:5,000 photographs. This pattern was repeated, providing two sets of data for each operator.

In this measurement program, the operators measured and recorded the parallax of the top and the base of each tree. The conversion of these data into tree heights was carried out by the project leader. A further curb on memory bias was provided by a rule that stated that no

* The author wishes to acknowledge the assistance given him by E. Fred Schultz, Jr., Professor of Biometry at the Alabama Polytechnic Institute, in the design and analysis of this study.

† The parallax wedge was printed in red on film. It was manufactured by the Division of Engineering, U. S. Forest Service.

‡ A "Contour Finder," manufactured by the Abrams Instrument Corporation, Lansing, Mich.

more than one set of 14 trees could be measured on any one day.

Analysis of the Data

Originally it was planned to use, as the dependent variable, the difference (error) between the measured differential parallax and the differential parallax corresponding to the true height. When this was done, however, it was found that the variances of the errors differed significantly between the scales, making it impossible to use conventional tests for the significance of differences or for the relative efficiency of regressions. A typical example of such differences in variance is shown in Figure 1. When, however, the dependent variable was changed to the difference (error) between the true height and the photographically determined tree height, this heterogeneity of variance disappeared, making it possible to use conventional methods of testing. For this reason the error in height was recognized as the dependent variable in this study. A coding factor of 100 was added to each error to eliminate negative values.

Due to the fact that three operators had to be used, only one of whom completed the entire sequence on both instruments, it was impossible to evaluate the differences between the instruments, since they were confounded with operator differences. Because of this the experimental design was changed from one all-inclusive study to two sub-studies, one for each instrument. Each of these sub-studies had two operators, two cycles of measurements, four scales, and 14 trees.

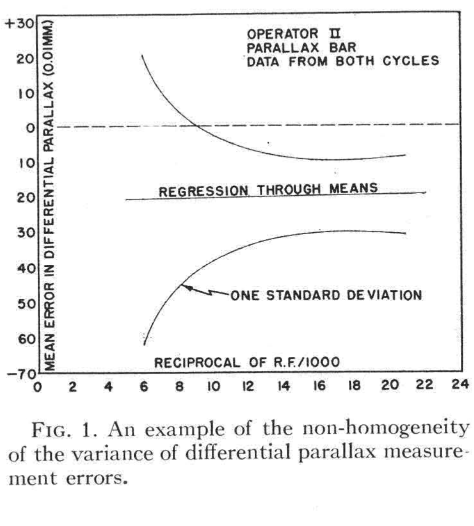

Fig. 1. An example of the non-homogeneity of the variance of differential parallax measurement errors.

Upon completion of the measurement operations the data were subjected to analyses of variance. In order to reduce cross-classification between the independent variables and to arrive at valid testing terms, it was necessary to assume arbitrarily that the scales and the trees were fixed rather than random variables. This was justified, since repeated measurements were made of the same trees and on the same photographs that provided a measure of repeatability of the measurements. This was the reason for the organization of the analyses of variance shown in Tables 2 and 3.

The discrepancies in the degrees of freedom in these analyses of variance were caused by missing observations. These gaps in data occurred because of the lack of stereoscopic cover on one tree on the 1:15,000 photographs and to the inability of one of the operators to make measurements with the parallax wedge in narrow valleys. In the latter case, the gaps were filled by conventional "missing plot" procedures.

With the analyses of variance organized in this manner, the testing program became similar to that used in a split plot design. The "main plots" were the operators and the cycles. The differences between the component elements of these terms were tested with the $C \times O$ interaction. In the case of the parallax wedge, the evidence indicated that both operators performed in much the same way. Their biases, if any, were approximately equal and of the same sign. In addition, the evidence from the cycles indicated that both operators were "experienced" and were no longer learning (i.e. they were in the flat portion of the learning curve). In the case of the parallax bar, the evidence again indicated that the operators were in the flat portion of the learning curve. In contrast with the parallax wedge, however, the probability of an actual difference in the performance of the two operators was sufficiently high to suggest the presence of operator bias in some form.

If performances of operators are subjected to quality control procedures, the presence or absence of operator bias can quickly be determined. This was done with the present data yielding the results shown in Figures 2 and 3. The standard deviations upon which these control charts were

TABLE 2

ANALYSIS OF VARIANCE, ERRORS IN THE TREE HEIGHT MEASUREMENTS MADE WITH THE PARALLAX BAR

Source of Variation	*Pooled Degrees of Freedom*	*Degrees of Freedom*	*Pooled Mean Square*	*Mean Square*	*F-Ratio*	*Probability of a Real Difference*
Total		219				
Operators (O)		1		5,214.0	162.937	>0.950
Cycles (C)		1		106.0	3.313	<0.900
$C\times O$		1		32.0		
Treatments (D)	54		208.5			
Trees (T)		13		544.1	6.025	>0.995
Scales (S)		3		74.0	0.819	<0.900
$T\times S$		38		104.4	1.156	<0.900
$D\times O$	54		90.3			
$T\times O$		13		84.4	1.182	<0.900
$S\times O$		3		4.3	0.035	<0.900
$T\times S\times O$		38		99.1	1.694	<0.900
$D\times C$	54		90.9			
$T\times C$		13		64.6	0.905	<0.900
$S\times C$		3		411.3	3.380	<0.900
$T\times S\times C$		38		74.7	1.280	<0.900
$D\times C\times O$	54		65.1			
$T\times C\times O$		13		71.4	1.221	<0.900
$S\times C\times O$		3		121.7	2.080	<0.900
$T\times S\times C\times O$		38		58.5		

based were derived from the pooled residual variance for each operator with each instrument following the pattern of the analysis of variance shown in Table 4. The control bands on the control chart lie at ±2 and ±3 standard errors from the mean, based on samples of 14 trees each.

An examination of these figures will reveal that Operator I was in control with both instruments, but he had a slight tendency toward excessively high readings. The mean of all the readings made with the parallax wedge was 100.6, indicating a bias of +0.6 foot (see Table 5). With the parallax bar the bias was +0.4 foot.

Operator II, using the parallax wedge, showed a tendency toward wildness. This wildness, however, became less as the work progressed, indicating, perhaps, that the operator was not yet in the flat portion of the learning curve. It is also possible that it reflects a psychological reaction toward making measurements of this type for serious purposes rather than for a student problem. This operator also revealed a positive bias of about 3.9 feet.

Operator III, using the parallax bar, showed a very definite negative bias of approximately 9.4 feet. Insofar as scatter was concerned, however, he was in control.

In the "subplots" portion of the analyses of variance, the main factors were trees and scales. The interactions between these variables and the main plot variables provided the testing terms. In the customary manner, it was assumed that the third order interaction had no real meaning and could be considered as unexplained residual variation. As a result, with both instruments, it was used as the initial testing term. When it was applied to the $T\times C\times O$ terms, it was found that in both cases the probabilities of real ef-

TABLE 3

ANALYSIS OF VARIANCE, ERRORS IN TREE HEIGHT MEASUREMENTS MADE WITH THE PARALLAX WEDGE

Source of Variation	*Pooled Degrees of Freedom*	*Degrees of Freedom*	*Pooled Mean Square*	*Mean Square*	*F-Ratio*	*Probability of a Real Difference*
Total		215				
Operators (O)		1		576.0	28.800	<0.900
Cycles (C)		1		84.0	4.200	<0.900
$C\times O$		1		20.0		
Treatments (D)	54		172.5			
Trees (T)		13		419.7	4.059	>0.995
Scales (S)		3		141.3	1,367	<0.900
$T\times S$		38		90.4	0.874	<0.900
$D\times O$	52		103.4			
$T\times O$		13		28.5	0.418	<0.900
$S\times O$		3		718.0	4.110	<0.900
$T\times S\times O$		36		79.3	1.618	<0.900
$D\times C$	54		65.4			
$T\times C$		13		64.7	0.949	<0.900
$S\times C$		3		96.0	0.550	<0.900
$T\times S\times C$		33		63.3	1.292	<0.900
$D\times C\times O$	52		61.0			
$T\times C\times O$		13		68.2	1.392	<0.900
$S\times C\times O$		3		174.7	3.565	0.975
$T\times S\times C\times O$		36		49.0		

fects associated with these terms were less than 90 chances out of 100, and, consequently, these terms were considered non-significant. In the case of the parallax bar, this level of probability also applied to the $S\times C\times O$ term. However, with the parallax wedge, the probability of the existence of a real effect rose to 97.5 chances out of 100. If this was the case, the effect of scale would change with the cycle and with operator in a repeatable manner. It was felt that this was rather unlikely, especially, since so few degrees of freedom were involved, and since the effect did not approach significance with the other instrument. Consequently, it was assumed that this result was due to random chance and the significance was ignored. These interpretations yielded the conclusion that the second order interactions, like the third order, represented only random variability or error and could be used to test the first order interactions.

In the next sequence of tests, $T\times C\times O$ was used to test $T\times C$, $S\times C\times O$ was used to test $S\times C$, and $T\times S\times C\times O$ was used to test $T\times S\times C$. In no case did the level of significance rise to the point where an effect due to one of these interactions could be recognized. In other words, the effect, if any, of trees, scales, and their interaction, did not change with cycles of measurement.

This procedure was repeated for the $D\times O$ group with much the same results. The effect, if any, of trees, scales, and their interaction, apparently did not change with operators.

At this point, it was possible to use either the $D\times O$ or the $D\times C$ groups to test the treatments themselves. In both cases the component mean squares were found to be non-significant and homogeneous, making it possible to pool the sums of squares and degrees of freedom so as to get single testing terms. The choice

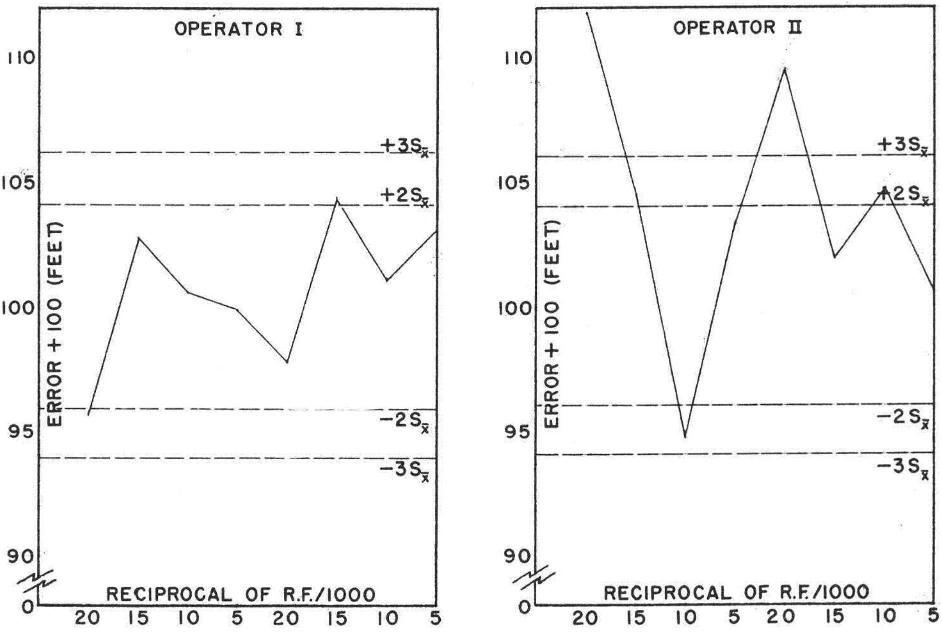

FIG. 2. Control charts for the parallax wedge.

of the pooled $D \times O$ group as the testing term was based on the observation that, in the parallax wedge analysis, the mean square for this group was larger than that for the $D \times C$ group. Use of the $D \times O$ group would yield more conservative F-ratio values, thus reducing the possibility of misinterpretation of the data.

In the case of the parallax bar analysis, there was practically no difference be-

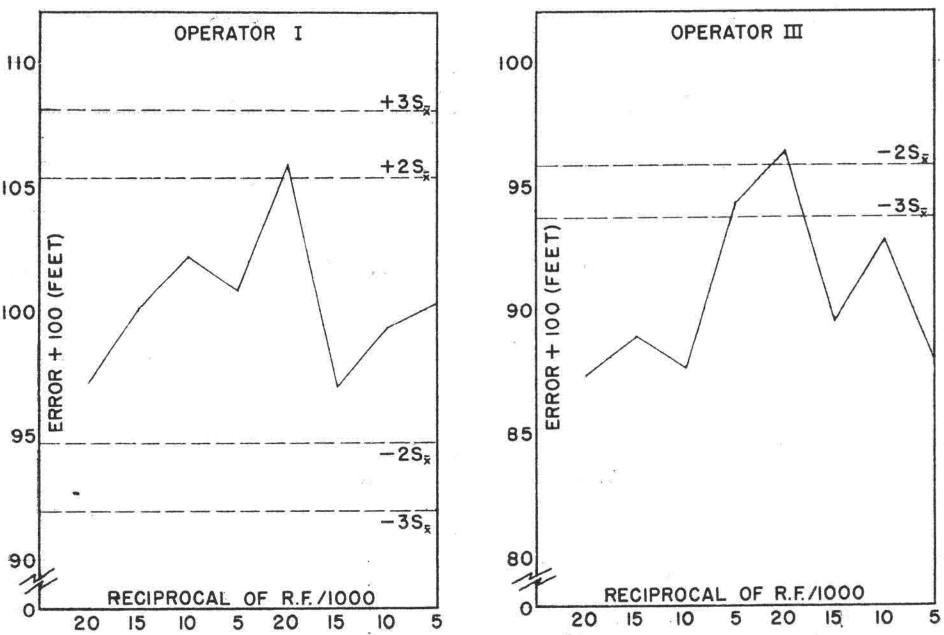

FIG. 3. Control charts for the parallax bar.

TABLE 4

COMPUTATION OF THE STANDARD ERROR OF THE MEAN FOR ERRORS IN TREE HEIGHT MEASUREMENT. OPERATOR I ON THE PARALLAX WEDGE. ANALYSIS OF VARIANCE

Source of Variation	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*
Total	109	9,478	
Cycles	1	93	
Scales	3	671	
$S \times C$	3	25	
Trees	13	3,382	
$T \times C$, $T \times S$, $T \times S \times C$	89	5,307	59.6

COMPUTATION

$$S_{\bar{x}} = \pm \sqrt{\frac{S.S.}{(d.f.)(n)}} = \pm \sqrt{\frac{5,307}{(89)(14)}} = \pm 2.064 \text{ feet}$$

Where $S.S.$ = Sum of squares
$d.f.$ = Degrees of freedom
n = Sample size

tween the mean squares of the two groups. For this reason, and in order to keep the analyses of variance of the two instruments as nearly alike as possible, the pooled $D \times O$ group was also used as the testing term in the parallax bar analysis.

With both instruments the probability of a real effect of scale on the precision of tree-height measurement was less than 90 chances out of 100. In the case of the trees, however, a very high probability developed that the means of the several measurements of the individual trees differed in some systematic manner. This reflected some, as yet, undefined relationship between the error in measurement and tree size, species, crown shape, or other characteristic. The analyses of variance and the tests of the $T \times S$ interactions supplied evidence that the unknown factor was not associated with scale. An examination of the data revealed some effect of crown shape (i.e. the height of tree #14, a red cedar with a long tapering crown, was consistently underestimated). However, because of the very few trees in the study, no generalizations regarding the effect of crown shape on error could be made. For the same reason no statements could be made concerning the relationship of species and error. It was possible, however, to study the effect of tree *size* on error by use of regression analysis. This was done by introducing a linear regression of error on true tree-height into each term in the analyses of variance in which "trees" were involved. The modified analyses of variance appear in Tables 6 and 7.

Each of the reductions due to these re-

TABLE 5

SYSTEMATIC AND RANDOM ERRORS OF INDIVIDUAL TREE HEIGHT MEASUREMENTS. THE FOUR SCALES POOLED

Operator	*Instrument*	*Systematic Error (Bias)*	*Standard Deviation*
		Feet	*Feet*
I	Parallax wedge	+0.6	± 7.72
II	Parallax wedge	+3.9	± 7.47
I	Parallax bar	+0.4	±10.06
III	Parallax bar	−9.4	± 7.89

TABLE 6

ANALYSIS OF VARIANCE, ERRORS IN TREE HEIGHT MEASUREMENTS MADE WITH THE PARALLAX BAR

Source of Variation	*Pooled Degrees of Freedom*	*Pooled Degrees of Freedom*	*Degrees of Freedom*	*Pooled Mean Square*	*Pooled Mean Square*	*Mean Square*	*F*[a] *Ratio*	*F*[b] *Ratio*	*Probability of a Real Effect*	*Probability of a Real Effect*
Total			219							
Operators (O)			1			5,214.0		162.937		>0.950
Cycles (C)			1			106.0		3.313		<0.900
$C\times O$			1			32.0				
Treatments (D)	54			208.5						
Trees (T)		13			544.1			6.025		>0.995
Linear[c]			1			35.0	0.060	0.388	<0.900	<0.900
Residual			12			586.5		6.495		>0.995
Scales (S)		3			74.0			0.819		<0.900
$T\times S$		38			104.4			1.156		<0.900
Linear $\times S$			3			52.7	0.484	0.584	<0.900	<0.900
Residual $\times S$			35			108.8		1.205		<0.900
$D\times O$	54			90.3						
$T\times O$		13			84.4			1.182		<0.900
Linear $\times O$			1			199.0	2.660		<0.900	
Residual $\times O$			12			74.8				
$S\times O$		3			4.3			0.035		<0.900
$T\times S\times O$		38			99.1			1.694		<0.900
Linear $\times S\times O$			3			61.7	0.603		<0.900	
Residual $\times S\times O$			35			102.3				
$D\times C$	54			90.9						
$T\times C$		13			64.6			0.905		<0.900
Linear $\times C$			1			82.0	1.297		<0.900	
Residual $\times C$			12			63.2				
$S\times C$		3			411.3			3.380		<0.900
$T\times S\times C$		38			74.7			1.280		<0.900
Linear $\times S\times C$			3			94.3	1.292		<0.900	
Residual $\times S\times C$			35			73.0				
$D\times C\times O$	54			65.1						
$T\times C\times O$		13			71.4			1.221		<0.900
Linear $\times C\times O$			1			286.0	5.346		>0.950	
Residual $\times C\times O$			12			53.5				
$S\times C\times O$		3			121.7			2.080		<0.900
$T\times S\times C\times O$		38			58.5					
Linear $\times S\times C\times O$			3			85.7	1.525		<0.900	
Residual $\times S\times C\times O$			35			56.2				

[a] Mean square of linear/Mean square of residual.
[b] Mean square of item/Mean square of $C\times O$, $D\times O$, $D\times C$, or $D\times C\times O$.
[c] The reduction in the sum of squares due to the regression of error on true tree height.

gressions was initially tested with the accompanying residual sum of squares. As can be seen in the majority of cases, the reductions were non-significant, indicating that tree-height had little effect on the error associated with the respective terms. In the cases where the F-ratios indicated high probabilities of real effects of tree-height on error, it was found that the pattern did not remain constant with both instruments. In addition, they occurred in terms that in their unmodified form had already shown themselves to be non-significant. For these reasons, the indications of significant effects were ignored and the assumption was made that tree-height had little or no effect on the error of its measurement. When the mean squares associated with the linear terms were tested with the corresponding $D\times O$, $D\times C$, or $D\times C\times O$ terms, a similar pattern appeared. In only one case, considering both instruments, did the probability level rise as high as 0.95. This occurred with the "linear within trees" with the parallax wedge. The corresponding value with the parallax bar was less than 0.90. For this reason it is difficult to make a statement concerning the effect of tree-height on error. The evidence seems to indicate that, if a relationship exists, it is only of minor importance. Unfortunately, the reasons for this relationship cannot be evaluated with the present data. It is possible that with ten or twenty times as many sample trees an approach could be made to the solution of this problem. In any case, from the evidence of earlier

TABLE 7

ANALYSIS OF VARIANCE, ERRORS IN TREE HEIGHT MEASUREMENTS MADE WITH THE PARALLAX WEDGE

Source of Variation	*Pooled Degrees of Freedom*	*Pooled Degrees of Freedom*	*Degrees of Freedom*	*Pooled Mean Square*	*Pooled Mean Square*	*Mean Square*	*F-Ratio*[a]	*F-Ratio*[b]	*Probability of a Real Effect*	*Probability of a Real Effect*
Total			215							
Operators (O)			1			576.0		28.800		<0.900
Cycles (C)			1			84.0		4.200		<0.900
$C \times O$			1			20.0				
Treatments (D)	54			172.5						
Trees (T)		13			419.7			4.059		>0.995
Linear[c]			1			544.0	1.329	5.261	<0.900	>0.950
Residual			12			409.3		3.958		>0.995
Scales (S)		3			141.3			1.367		<0.900
$T \times S$		38			90.4			0.874		<0.900
Linear $\times S$			3			197.7	2.435	1.912	<0.950	<0.900
Residual $\times S$			35			81.2		0.785		<0.900
$D \times O$	52			103.4						
$T \times O$		13			28.5			0.418		<0.900
Linear $\times O$			1			17.0	0.578		<0.900	
Residual $\times O$			12			29.4				
$S \times O$		3			718.0			4.110		<0.900
$T \times S \times O$		36			79.3			1.618		<0.900
Linear $\times S \times O$			3			83.7	1.061		<0.900	
Residual $\times S \times O$			33			78.9				
$D \times C$	54			65.4						
$T \times C$		13			64.7			0.949		<0.900
Linear $\times C$			1			136.0	2.317		<0.900	
Residual $\times C$			12			58.7				
$S \times C$		3			96.0			0.550		<0.900
$T \times S \times C$		38			63.3			1.292		<0.900
Linear $\times S \times C$			3			90.3	1.483		<0.900	
Residual $\times S \times C$			35			60.9				
$D \times C \times O$	52			61.0						
$T \times C \times O$		13			68.2			1.392		<0.900
Linear $\times C \times O$			1			233.0	4.283		<0.900	
Residual $\times C \times O$			12			54.4				
$S \times C \times O$		3			174.7			3.565		0.975
$T \times S \times C \times O$		36			49.0					
Linear $\times S \times C \times O$			3			253.0	8.322		>0.995	
Residual $\times S \times C \times O$			33			30.4				

[a] Mean square of linear/Mean square of residual.
[b] Mean square of item/Mean square of $C \times O$, $D \times O$, $D \times C$, or $D \times C \times O$.
[c] The reduction in the sum of squares due to the regression of error on true tree height.

work and from theoretical considerations, it appears that the relationship is probably associated with crown shape and, consequently, tree species.

DISCUSSION OF RESULTS

Because of the defect in the statistical design caused by the inability of one of the operators to complete the work on both instruments, it was impossible to make a valid test for differences between the two instruments. However, an examination of the data and the analyses, especially the quality control charts, reveals that the two instruments yielded surprisingly similar results. This is particularly true when corrections are made for operator bias.

Getchel and Young's (2) study with the parallax bar and parallax wedge revealed no significant differences with respect to bias or variance. Worley and Landis (9), using the same instruments, found some difference but, because of faulty experimental design, this could be confounded with operator variability. The interesting thing about this latter study is that the simpler instrument had the better performance. If one compares the variance data for the several instruments used in other studies, including precise plotters, it becomes evident that increasing instrumental complexity does not affect the precision of tree-height measurement in any marked manner. This is probably due to the fact that such measurements require very little lateral motion over the surface of the photograph so that the effect of tilt on the measurement is negligible. The provisions built into the more precise plotters for the purpose of reducing or eliminating the effect of tilt are not needed for spot height measurements. Consequently, the simple instruments are about as precise as the more complex for work of this type.

In addition there is a limit to the perception of parallax differences by the instrument operators. This limit is inherent in the operator, not in the instrument. Increasing instrumental complexity does nothing to improve this perception. Since this limit is usually in the neighborhood of 0.001 inch of parallax difference (8), any instrument capable of measuring this or a smaller magnitude theoretically would yield substantially the same results. This reflects the fact that the human limit, rather than the instrumental, has been attained.

There is a possibility that Schlatter's (5, 6) and Worley and Landis' (9) argument, that the presence of the stationary sloping line of dots in the stereomodel, associated with the parallax wedge, makes the judgement of the position of the top of the tree easier, acts to offset the crudeness of the wedge instruments when compared with the parallax bar.

The absence of a correlation between photographic scale and the error of individual tree-height measurements is rather surprising. Theoretically, two effects of scale can be expected: 1) that creating a bias through the apparent loss of tree height associated with resolution limitations; and 2) that creating a change in the magnitude of the error variance by the change in the tree-height equivalent of the least reading of the instrument. Spurr (7) has discussed this problem and has published tables of the expected biases and variances when making tree height measurements under certain specified conditions and on photographs of certain scales. The theoretical pattern is clear. In this study, however, the theoretical pattern did not appear.

The absence of a bias associated with scale was probably due to the fact that few of the trees had slender crowns and, consequently, little height was lost because of lack of resolution. The absence of an effect on variability is more difficult to explain. In its original form this study was designed to use the error in differential parallax as the dependent variable, in order to prevent the introduction of heterogeneity of error variance, caused by the differences in scale, into the analysis. At that time it was thought that scale would have little effect on the parallax measurements themselves since they are essentially linear measurements between two points on a flat surface. When the data were assembled, however, a scale effect became evident (see Figure 1). As the scale increased the variance of the error in *differential parallax* also increased. The transformation of the differential parallax data into tree height data eliminated the heterogeneity of variance and permitted the subsequent analyses. Apparently the scale effect described by Spurr is offset in practice by increased scatter as the scale increases. It is entirely possible, however, that the use of operators experienced in the use of large scale photographs would remove this effect. In other words, it is possible that the change in the variance of differential parallax errors may reflect a learning curve situation.

Using the information in Table 5, it is possible to correct for operator bias and also to determine the number of trees that would have to be measured in a stand to achieve a predetermined precision of *average stand height* at a given probability level. This procedure could also be applied to the determination of the height of an individual tree but it must be remembered that an undefined individual tree bias, revealed by the analyses of variance, would remain as a constant uncompensated error. In contrast with an individual tree, stands usually contain trees representing a variety of crown shapes. When the heights of these trees are measured, in order to determine average stand heights, each contributes a different bias. In the averaging operation, a certain amount of compensation takes place, reducing the bias and making it less important. For this reason average stand heights are less subject to error than individual tree heights, even though both are based on the same number of individual measurements.

Summary and Conclusions

The evidence of this study indicates that:

1) Error in tree height measurement on aerial photographs is not associated with photographic scale, at least in

the range from 1:5,000 to 1:20,000.
2) Error is not associated with cycles of measurements except when an operator is still learning to make measurements.
3) Error is associated with some tree characteristic, probably crown shape, but no further information can be obtained from the present data.
4) Error may be associated in a minor way with tree size (height).
5) Error is associated with the operators

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Expansion by Gordon Enterprises

The purchase of Q.O.S. Corporation Photogrammetric Division, has been announced by Gordon Enterprises' president Alan Gordon. This includes acquisition of all physical assets and goodwill of the New York concern, which has specialized in the manufacture of photographic measuring devices for over 17 years.

Prism stereoscopes, portable pocket stereoscopes, accessory binoculars, parallax bars, stereocomparagraphs and other instruments used in the measurement of photographs will be manufactured by Gordon Enterprises.

The line of photogrammetric instruments of the Q.O.S. Corporation will be combined with an already extensive instrument line which Gordon now manufactures for the military, aerial photography, and missile data-recording professions.

Installation of the Q.O.S. Corporation's equipment and manufacturing enterprise in the Gordon firm's North Hollywood plant will bring to the West Coast the only photogrammetric instrument manufacturing enterprise to be located in the West.

Kodak Introduces $99.50 Verifax Bantam Copier Ideal for Economical "Point-of-Need" Copying

Eastman Kodak Company has introduced a compact 14-pound office copier—the Verifax Bantam Copier—priced at $99.50.

Kodak officials expect that the low-priced Bantam will cut by one-third the cost of a decentralized, multiple copier system for larger companies.

The inexpensive Verifax Bantam Copier, which will be available from Kodak Verifax dealers in March, accepts originals up to $8\frac{1}{2}'' \times 11''$. It embodies new simplicity of design and functional copying features, and is the first Verifax Copier to employ a curved glass platen.

With compact base dimensions, $13\frac{1}{4}'' \times 17\frac{7}{8}''$, the Bantam makes the same multiple, photo-exact copies that typify all four models in the Verifax Copier line. Up to five copies of any typed, drawn, written, or printed original may be made on the Verifax Bantam Copier at a materials cost of about $2\frac{1}{2}$ cents per copy.

Capable of making intermediates or masters on Verifax Translucent Copy Paper for use in diazo-type printers, the Bantam is also adaptable for use with the Verifax method of producing offset masters for office-type duplicators.