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B8 Contouring Accuracy*

Although the Wild B8 plotter was developed for mapping at small and medium scales, it can also be used for large scales.

(Abstract on next page)

INTRODUCTION

EXPERIMENTAL STUDIES in connection with small-scale mapping were organized during the period 1960–1964 by the International Society of Photogrammetry under the direction of Working Group of Commission IV. South Africa's contribution, which was fully reported at the International Congress held in Lisbon in 1964, consisted of an investigation into the accuracy of contouring at small scales using various types of plotting equipment. The interesting results obtained prompted an extension of this investigation into mapping at scales of the order of 1/2,500 and 1/1,200.

Much has been written and spoken regarding the accuracy of height determination and contouring using photogrammetric methods and equipment, but more often than not the results and conclusions have been based on theoretical surmise rather than practical considerations, such as using observations to grid plates rather than actual photographs to detei mine heighting accuracy. The work done by Scholz [1] in Germany and Blachut, Tewinkel and others [2] on the Renfrew Test are notable exceptions, however, and indicated the value of tests conducted under normal production conditions.

The tests under discussion in this paper were undertaken as far as possible under those standard conditions that would be encountered in practice, and no special precautions nor improvements to methods, equipment and procedures were made. Normal survey methods were used to establish the ground control points (which were not marked prior to photography), the photography was exposed under standard conditions, no especial precautions were taken during the preparation of the diapositives nor was any allowance made for the effects of earth curvature, refraction and lens distortion. The study utilized relatively inexperienced machine operators who, after testing, did not reveal exceptional stereoscopic vision on their part, and standard empirical relative and absolute orientation procedures were employed prior to plotting.

In the case of the ground tacheometric survey, however, precautions were taken to ensure the accuracy of the contour plans which were to yield the "true" values with which the photogrammetric surveys were to be compared. The actual comparison was made using the method devised by Lindig and others as set out by Singels [3]. The method was modified somewhat to enable the effect of any systematic error to be eliminated prior to determining the standard deviations. It is considered that this method is as good as any in yielding a result of practical value.

SURVEY AND PHOTOGRAMMETRIC OPERATIONS

Area I (see Table 1) is a portion of bare hillside above the village of Mamre about forty miles north of Cape Town. The 740 ft. contour was carefully set out on the ground using a spirit level. At the same time sufficient spotheights were similarly determined to enable the 730 and 750 ft. contours to be accurately interpolated. A plan of these contours was plotted at 1/2,500. The relative orientation was undertaken using a standard empirical method and after absolute orientation of the model, the height readings at the ground control points resulted in discrepancies considerably less than 1 ft. At the model scale used it was possible to estimate

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heights to a decimal of a foot. After the 730, 740 and 750 ft. contours had been plotted in the conventional manner by keeping the floating mark in contact with the model at these elevations, photogrammetric spot-heights were plotted from which contours could be interpolated in the normal manner. Two comparisons with the ground contours were therefore possible and these are shown in Figure 1. The standard deviation of a height reading (not a height determination) for the particular machine-operator combination determined from the internal consistency of a large number of observations on the model was approximately 0.5 ft. or .012% *H*. check on the observation of each spot elevation. The stereomodel was then oriented using the same orientation procedure as with Area I, the ground control points, being precise points of detail such as sawn-off tree-stumps, etc.

The maximum discrepancy on any ground control point was less than 0.4 ft. and the mean discrepancy less than 0.2 ft. A different operator was used for Area II and the standard deviation of a height reading in this case was 0.34 ft. or .013% *H*. At the model scale used (1/3,000) heights could be estimated to a decimal of a foot. Contours were plotted at five foot vertical intervals over a total height range of 375 ft., covering the three areas. As this Area I after the contours had been plotted directly, spotheights were also determined photogrammetrically for the subsequent interpolation of the contours. The discrepancies between the contours determined by the various methods for typical portions of areas IIA, IIB and IIC are illustrated in Figure 2.

ABSTRACT: *Two areas were contoured with a Wild B8 Aviograph at scales 1/2,500 and 1/1,200 using different photography and operators. The contours were compared with those determined using classical ground methods and the standard deviations in height and position determined by means of the method devised by Lindig. These standard deviations are then related to the flying height, the values showing little difference for the various experiments made. For medium slopes in the range 7°–15° using a B8 plotter and wide-angle photography, the standard deviation in height of a contour is established as 0.03% of the flying height, and the systematic error in the height of a contour is found to be 0.02%* H. *Using the elevations of approximately 300 ground points, the standard deviation of height determination is established as .021% of the flying height with a systematic error of the machine-operator combination of less than half this amount. A comparison is also made between contours interpolated from photogrammetric spotheights and those from tacheometric spotheights. For slopes in the range 7°–15° it is decidedly disadvantageous to use this method. Finally the ability of the B8 to comply with a typical specification is appraised.*

Area II is located in close proximity to the University of Cape Town, comprising portions of Rhodes Estate on the slopes of Devil's Peak. Three portions of the overlap designated A, B and C covering differing terrain types (see Table 2) were selected and a precise tacheometric survey undertaken at 1/1,200 using a double staff developed by Professor Menzies [4] to provide an accurate

Since a large number of spotheights were

TABLE 1

Area	*Camera*	*Focal Length, mm.*	*Diapositive*	*Flying Height above Ground ft. (H)*	*Model Scale*	*Plotting Scale*	*Contour Interval ft.*
I	Wild RC5A 205	152.83	Glass	4,000	1/5,000	1/2,500	10
IIA, IIB, IIC	Zeiss RMK 21085	132.09	Film	2,600	1/3,000	1/1,200	5

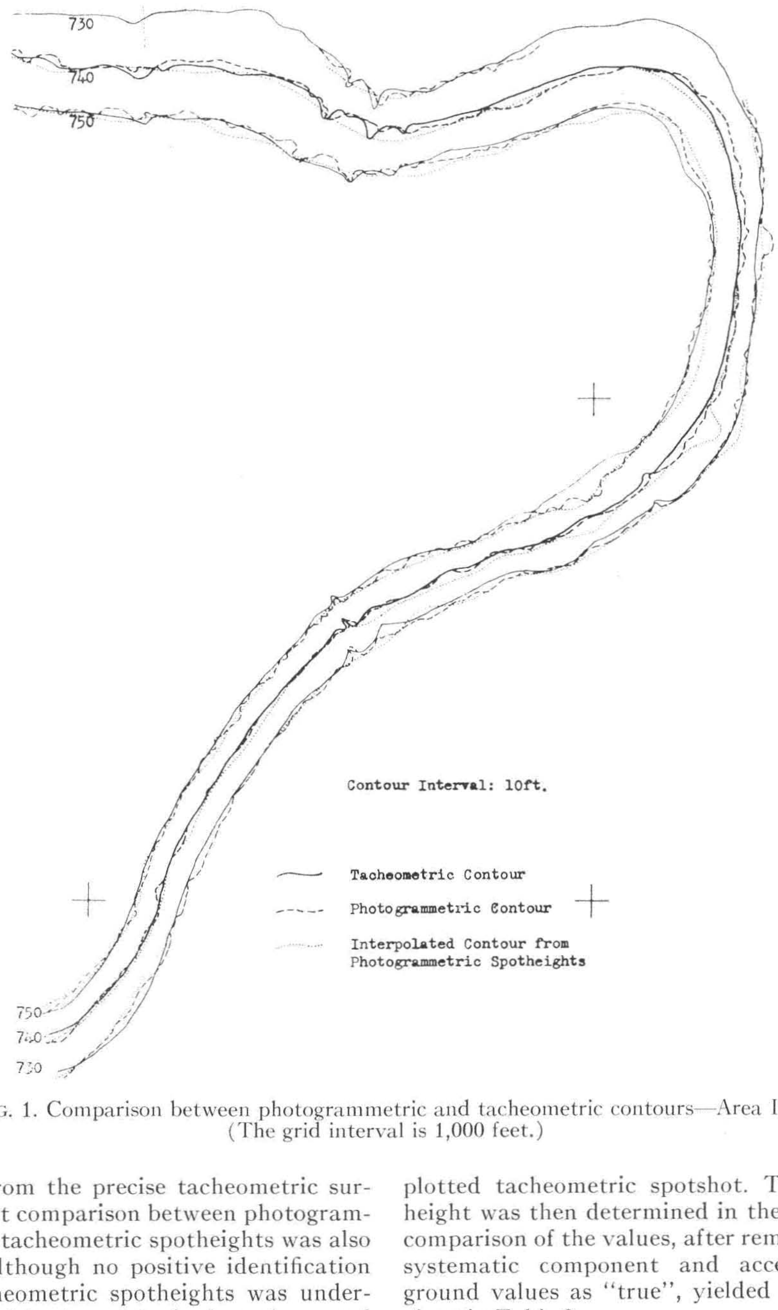

FIG. 1. Comparison between photogrammetric and tacheometric contours—Area II. (The grid interval is 1,000 feet.)

available from the precise tacheometric survey, a direct comparison between photogrammetric and tacheometric spotheights was also possible. Although no positive identification of the tacheometric spotheights was undertaken, it is felt the method adopted ensured that the photogrammetric spotheights were taken within a foot or so of where the staff was held and that furthermore any misplacing of the tracing point would result in an error of a random rather than a systematic nature. To ensure accurate relocation of the spotheight in the plotter, the tracing pencil on the pantograph was fitted with a mirror and lens to ensure accurate coincidence with the plotted tacheometric spotshot. The ground height was then determined in the plotter. A comparison of the values, after removal of the systematic component and accepting the ground values as "true", yielded the results given in Table 2.

The variation in the systematic errors is to be expected with the variation in terrain surface and slope and the mean standard deviation of 0.5 ft. or .019% H is considered reasonable. Corresponding results for an A8 plotter on the Renfrew test after elimination of systematic error were—Systemetic .008% H and mean standard deviation .015% H.

Using the Lindig method, well over three

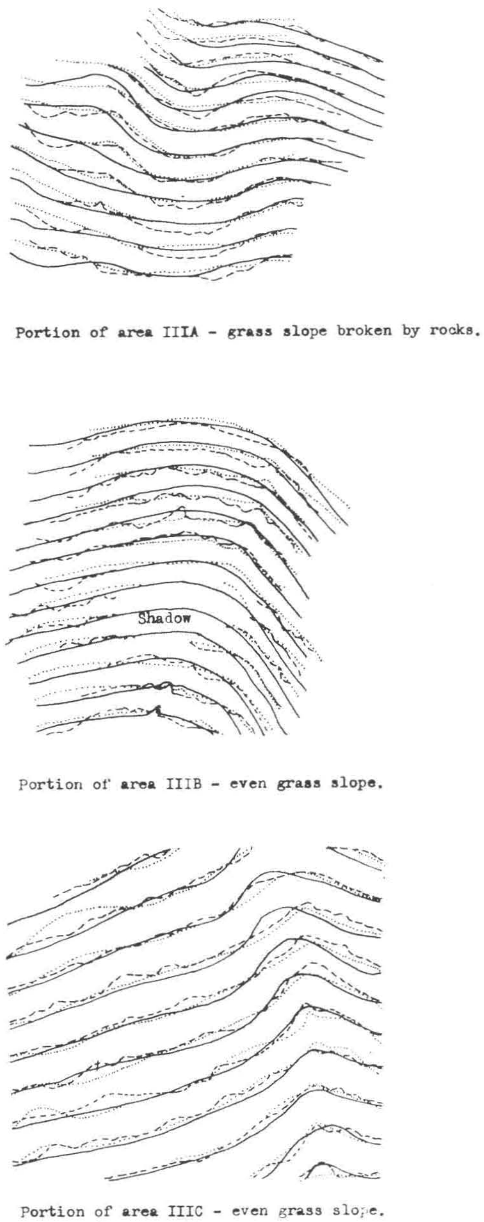

FIG. 2. Comparison between photogrammetric and tacheometric contours—Area III. Contour interval: 5 feet. The original scale was 1/1,200, but is reproduced here at about 1/2,200. The legend is the same as that shown in Figure 1.

hundred comparisons were made at regular intervals along the contour lines. The contours as determined from the precise tacheometric survey were accepted as "true". From the measured differences between the "true" and photogrammetric contours, it was possible to determine the presence of any systematic height error as well as the standard deviations in position and height of the photogrammetric contours. Unfortunately time did not permit the extension of the investigation to determine the curvature and direction errors of the contours as well. The results of the comparisons are given in Tables 3 and 4.

ANALYSIS OF RESULTS

In examining these results it must be conceded that although the ground surveys have been accepted as correct, this is not the case. However, no useful purpose would be gained by endeavouring to establish the accuracy or otherwise of these ground surveys and they have been accepted as the best material with which to compare and establish the accuracy of photogrammetric methods of undertaking similar operations. Furthermore, it is not suggested that the results establish the absolute accuracy of the B8 in heighting and contouring, but rather that they afford the photogrammetrist with a reliable yardstick for the planning of photogrammetric operations so that the final result may be within any predetermined specification. For instance, it can be inferred for medium slopes in the range 7°–15°, using a B8 plotter with an operator of average ability and modern wide-angle cameras that (i) the standard deviation in height

TABLE 2

Area	*Nature of Surface*	*Average Slope*	*No. of Spotheights*	*Systematic Error*		*Standard Deviation of a Height Determination*	
				Ft.	*%H*	*Ft.*	*%H*
IIA	Grass broken by rocks	13°42′	44	+0.5	.019	0.5	.019
IIB	Even grass surface	12° 48′	66	+0.3	.011	0.6	.023
IIC	Even grass surface	9° 00′	175	<0.1	<.003	0.4	.015
Mean		11° 50′				0.5	.019

TABLE 3

COMPARISON OF DIRECT PHOTOGRAMMETRIC CONTOURING WITH TACHEOMETRIC CONTOURING

(i) Area	*(ii)* Average Slope	*(iii)* Contour Interval,	*(iv)* Flying Height *H*,	*(v)* Systematic Height Difference		*(vi)* Standard Deviation in Height of a Contour	
		Ft.	*Ft.*	*Ft.*	*%H*	*Ft.*	*%H*
I	7° 55′	10	4,000	+0.9	.023	1.1	.028
IIA	13° 42′	5	2,600	−0.3	.012	0.8	.038
IIB	12° 48′	5	2,600	−0.3	.012	0.9	.034
IIC	9° 00′	5	2,600	−1.0	.038	0.5	.018
Mean					.021		.029

of a contour would be of the order of .03% *H* for normal terrain surfaces, (ii) that the standard deviation in heighting a point would be of the order of .02% *H*, (iii) that the greatest vertical discrepancy in a contour which could be expected to occur in 90% of any checks that may be applied would be of the order of .06% *H*.

The systematic component of the differences between the contours varies as is to be expected with the camera used, the particular operator and also with terrain type, but in magnitude it appears to be of similar order. Factors such as earth curvature, lens distortion, refraction etc. will cause errors of a systematic nature which normally reach their maximum value in the center of the stereomodel, but their effect has been assessed as being well within the possible reading accuracy of the B8, i.e., about .02% *H*, and no account has therefore been taken of them.

Unfortunately the experiments could not be repeated in flatter areas and it is difficult to draw valid conclusions in this case. As the slope angle decreases the positional error varies as the cotangent of the slope and there is therefore a limit below which direct photogrammetric contouring is not feasible. Scholz [1] gives 2° as the limiting terrain slope for direct photogrammetric contouring and advocates that below this value photogrammetric spotheighting followed by interpolation of contours be resorted to. Interpolation tends to result in more generalised contours, but it must be remembered that in flat terrain, contours as such are rather meaningless and often confuse rather than assist the map user. Photogrammetric spotheighting followed by interpolation takes approximately three times as long as direct contouring and, as far as medium slopes are concerned, the accuracy is about 50% lower. For flatter terrain it is reasonable to conclude that the tables would be turned and a considerably higher accuracy attained than with direct contouring.

A comparison of the average values of the results obtained by Scholz [1], the Renfrew International Experiment and the present test is given in Table 5. At first sight it appears as if the B8 is only about one half as accurate as the A8 in contouring, but it must be borne in mind that Scholz used correction plates and other refinements, and in the

TABLE 4

COMPARISON OF CONTOURS INTERPOLATED FROM PHOTOGRAMMETRIC SPOTHEIGHTS WITH TACHEOMETRIC CONTOURING

(i) Area	*(ii)* Average Slope	*(iii)* Contour Interval,	*(iv)* Flying Height *H*,	*(v)* Systematic Height Difference		*(vi)* Standard Deviation in Height of a Contour	
		Ft.	*Ft.*	*Ft.*	*%H*	*Ft.*	*%H*
I	7° 55′	10	4,000	+0.4	.010	1.4	.035
IIA	13° 42′	5	2,600	−0.7	.027	1.3	.050
IIB	12° 48′	5	2.600	−0.8	.031	1.1	.042
IIC	9° 00′	5	2,600	−0.6	.023	1.4	.054
Mean					.023		.043

TABLE 5

COMPARISON OF THREE TESTS

Test	Instru-ment	Photo Scale	Average Slope	Standard Deviation in Height of a Contour %H
Schools	A8	1/12,000	4°00°	.015
Renfrew	A8	1/50,000	9°00	.012
U.C.T.	B8	1/5,200	11°50	.029

Renfrew experiment the A8 plotter gave the best result—even better than the first order A7. Commenting on the results of the latter test Tewinkel says "In general the tests proved considerably better than is normally obtained in productive work". It is considered therefore that the result for the B8 compares favourably with that for its more precise counterpart the A8, and also that the results represent those which can be expected under production conditions. It is of course a lower order machine costing approximately half the price of the A8 and comparisons are perhaps invidious under the circumstances.

Typical United States specifications demand that 90% of the errors evaluated on field checking contours should be within one half of the contour interval. Using modern statistical theory it can confidently be expected that 90% of the errors will be less than .06% *H* when both systematic errors and accidental errors in the height of a contour are considered together. To comply with specifications, these errors must be less than one half a contour interval. In other words a *C*-factor of 800 would then result.

This is an extremely conservative estimate and is considerably less than that obtained by Ing. Luis Struck of Mexico who assigns a *C*-factor of 1,200 to the B8 in the case of superwide angle plotting. The details of his derivation are not known: whether, for instance, he based his result simply on the standard deviation in the height of a contour or the standard deviation of height determination, or whether he took any account of systematic error. If the standard deviation of height determination only is considered, a *C*-factor of 2,500 would result. If the standard deviation in the height of a contour only is considered the *C*-factor becomes 1,600. It is believed, however, that these results are not strictly correct statistically.

In the case of large-scale plotting it is evident that the systematic error, particularly that due to terrain type, assumes much greater importance and tends to approach the same order as the standard deviation. This would account to a large extent for the somewhat low *C*-factor obtained when considering large-scale mapping. It must be emphasised again that the operators were relatively inexperienced and no sophisticated procedures were used at any stage of the experiment.

CONCLUSIONS

Although the Wild B8 Aviograph was developed primarily as an instrument for small and medium scale mapping purposes, it can be used with confidence on large scale surveys as well, providing appropriate photography is used, and the user should have no difficulty in complying with normal map and plan specifications.

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