ACCURACY OF STATOSCOPE-DATA - RESULTS FROM THE OEEPE-TEST "OBERSCHWABEN"

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1. INTRODUCTION

Auxiliary data have been known for a long time to be highly effective in aerial triangulation, |1| - |5|. Nevertheless they are not widely used in practice to this day.

Amongst auxiliary data especially APR and statoscope are most effective with regard to vertical accuracy of strips and blocks. When jointly included in simultaneous block-adjustment they are expected to improve accuracy and economy considerably beyond the present state of the technique |6|.

There exists only scarce information about the accuracies of statoscope- and APR-data which are generally believed to be in the order of 1.5 m - 4 m, depending on altitude and circumstances. Therefore, the European Research Organisation OEEPE included an investigation of the accuracy of statoscope data in the research program of the controlled aerial triangulation test "Oberschwaben" |7|. This paper presents a summary of experimental results as completed up to now.

2. ACCURACY OF STATOSCOPE DATA

2.1 - The test field "Oberschwaben" covers an area of 40.0 km x 62,5 km. It contains 540 signalized trigonometric points to be used as control points and check points. For about 470 of them the heights (Z) are known. In addition all tie points were signalized (as double targets) whence pin point flying was asked.

Aerial photography was taken in spring 1969 by Firma Häussermann, with Aero Commander 560 F. The test field was completely covered by both wide-angle and super-wide-angle photography of scale 1 : 28 000 (with Zeiss RMK 15/23 and Zeiss RMK 8.5/23), each mission giving a block of 15 strips of 60 % lateral overlap and 25 models each, with simultaneous recordings of the Zeiss statoscope S 2 |8|. Thus, the statoscope investigation distringuishes 2 sets of data:

- 15 strips of 62.5 km (25 models) each; wide-angle photography; flying height h_{rel} = 4 285 m, h_{abs} = 4 990 m
- 15 strips of 62.5 km (25 models) each; super-wide-angle photography; flying hight h_{rel} = 2 380 m, h_{abs} = 3 085 m.

There were 5 flying missions, on April 8th, 9th and May 12th for wide-angle-, on April 10th and 26th for super-wide-angle photography. Due to initial difficulties with pin point exposures the original photo-coverage had some gaps left. Reflying of 23 separate exposures was done without statoscope.

2.2 - Processing of statoscope data: The photographic statoscope recordings were read off paper prints of the aerial photographs, and converted to height differences Δh_{Stat}. The conversion factors, derived from the statoscope calibration and the reduction according to altitude, amounted to 1.05 m (w.a.) and 0.90 m (s.w.a.) respectively, per scale unit. Adding per strips a reference height H_o gave preliminary statoscope-heights:

$$Z_{Stat} = H_o + \Delta h_{Stat} \qquad (1)$$

No further corrections were applied, in particular no Henry correction (due to lack of drift angle recordings).

The preliminary statoscope heights Z_{Stat} (1) still refer essentially to unknown isobaric reference surfaces. They are compared with the heights Z_{PC} of the perspective centres (camera stations) as obtained from independent model block adjustments which utilized all given points as control (about 3 per model). The differences

$$\Delta Z = Z_{PC} - Z_{Stat} \qquad (2)$$

have been plotted for all strips separately, see examples in fig. 1

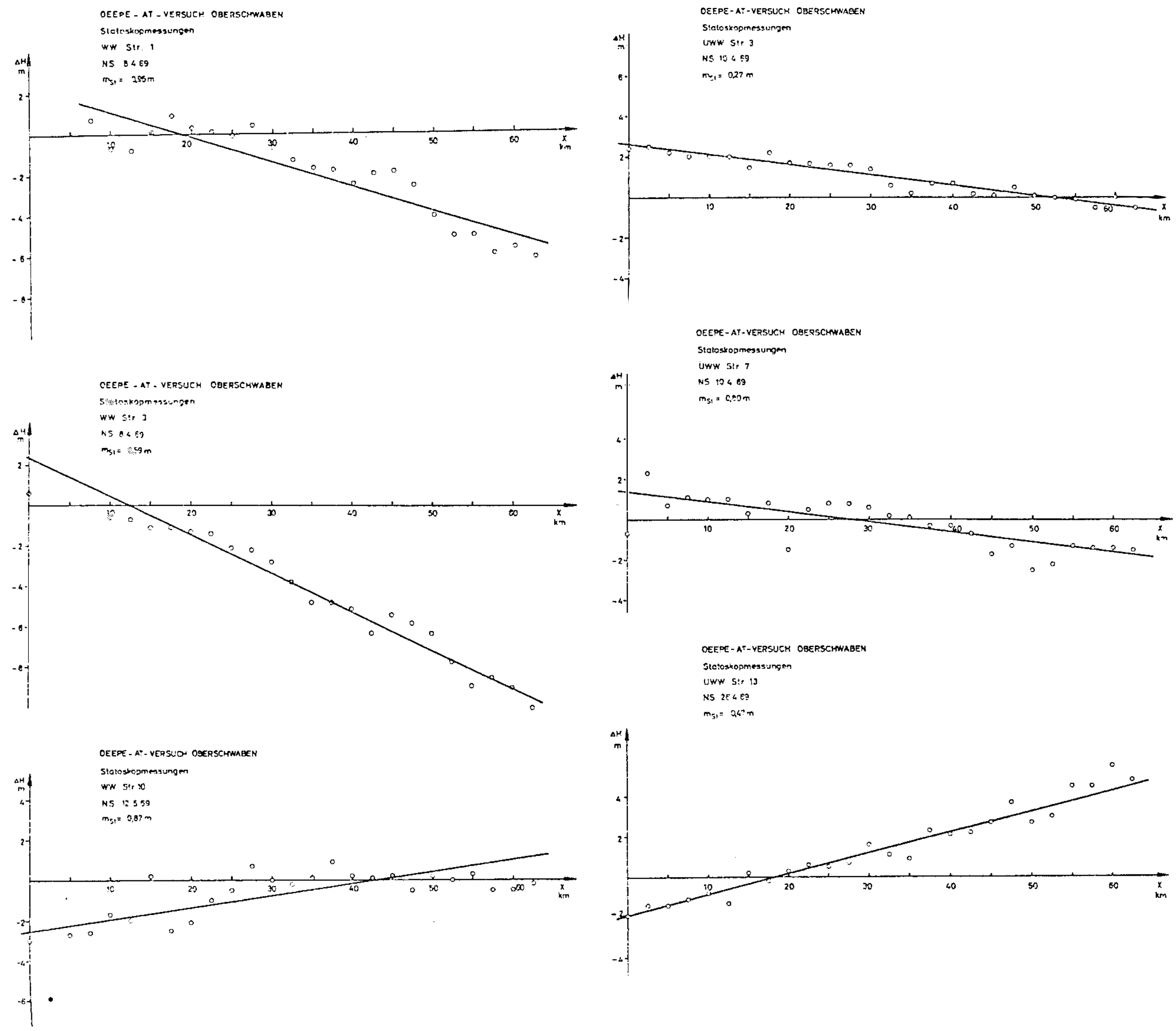

Figure 1 : OEEPE statoscope test "Oberschwaben" - Accuracy of statoscope data, 6 examples (Differences Z_{PC} - Z_{Stat} and residuals against linear approximation to isobaric surface.)

2.3 - Accuracy results: To the graphs of ΔZ-values (2) straight lines were fitted graphically, see fig. 1. They each represent a linear approximation to the isobaric surface. The residuals between ΔZ-values and straight lines

$$dZ = \Delta Z - (a_0 + a_1 x) \qquad (3)$$

are treated as errors of the statoscope measurements (against the isobaric reference), although they contain also the errors of the check-values Z_{PC} which are barely negligible. The residuals dZ are reduced per strip to root mean square values

$$m_{Stat} = \sqrt{\frac{[dZ.dZ]}{n - 2}} \qquad (4)$$

as collected in table 1. Altogether 23 values had to be excluded because of gross deviations, the causes of which are not known (such exclusion is permissible as gross errors would equally be detected in a practical case during the combined block-adjustment, see section 3).

The combined r.m.s. values of all strips amount to

m_{Stat} = 0.89 m (altitude 4 990 m, w.a.) (5a)

m_{Stat} = 0.79 m (altitude 3 085 m, s.w.a.) (5b)

The values (5) represent the direct experimental accuracies of the statoscope measurements with respect to isobaric surfaces. They refer to strip lengths of 62.5 km, and still contain possible error effects due to

- check heights of camera stations (!)
- non-linearity of isobaric profiles
- statoscope-calibration.

2.4 - Discussion of accuracy results: The first comment ought to point out that the obtained accuracy values are considerably better than originally expected. Also, they are rather representative, referring to 5 different flight missions, up to 5 weeks apart.

The accuracy results (5) correspond to 0.85 (w.a.) and 0.88 scale units (s.w.a.), respectively, of the statoscope recordings. Reduced to sea level the equivalent values are 0.59 m and 0.62 m. Thus the results are consistent with respect to altitude, and extrapolation seems to be permissible.

The accuracy results are close to the limits of resolution of the statoscope measuring system (involving stability of isobaric surface, pick-up of air-pressure, physical measuring process, registration and reading off dial). This is particularly true for some strips. 5 of the r.m.s. values m_{Stat} are equivalent to 0.3 (!) scale units. Consequently, in future, the measuring performance of statoscopes should be refined by, preferably, a factor of 2. Calibration values of less than 0.50 m/scale unit are desirable.

Linear approximations to isobaric surfaces have shown to be sufficiently representative, within the investigated distance range of 62.5 km. Although a few strips indicate a slight curvature in the order of 1 m there is altogether no significant evidence of curvature of an isobaric surface. This linear approximation is likely to be effective up to distances of at least 100 km.

The accuracy values m_{Stat} (5) spread over a rather wide range, for instance from 0.26 m - 1.30 m for the s.w.a. strips. 10 of the 15 s.w.a. strips have values between 0.26 m and 0.82 m, with a r.m.s. mean of 0.51 m. Clearly distinguished are the other 5 strips with values between 1.08 m and 1.30 m and a r.m.s. mean of 1.15 m. Thus we have obviously 2 sets of values, not belonging to the same population. According to a F-test the difference is significant on the 1 % level of significance. A similar disintegration, although not as marked, in 2 separate groups of accuracy results can be observed with the wide-angle strips. The total range of m_{Stat} values from 0.58 m - 1.30 m can be subdivided in a group of 12 values between 0.58 m and 0.94 m (r.m.s. mean 0.78 m) and 3 values between 1.18 m and 1.30 m (r.m.s. mean 1.23 m).

A variance analysis gave no significant relation of the 2 groups of poor values of m_{Stat} with any of the relevant flight parameters (date, flight direction, altitude). The only significance found relates to the observation that always the first two strips of the four main flight missions are disturbed. They show the largest or large values of m_{Stat}, see table 1. Omitting those 8 strips the r.m.s. means of the remaining values are:

m_{Stat} = 0.80 m $\hat{=}$ 0.76 scale units (altitude 4 990 m, w.a.) (6a)

m_{Stat} = 0.60 m $\hat{=}$ 0.67 scale units (altitude 3 085 m, s.w.a.) (6b)

In this case, only two strips with large values of m_{Stat} (1.16 m, 1.18 m) remain. The assumption seems valid that the statoscope was not sufficiently ready for measurement at the beginning of the flights, whatever the cause might have been. Consequently, results (6) can be considered realistic for experienced handling of statoscope-equipment.

A more detailed presentation of the accuracy results will be given in the complete OEEPE-report on the "Oberschwaben" statoscope investigation |9|.

Table 1 : OBERSCHWABEN flight missions and accuracy results of statoscope data

strip no.	flight mission		flight direction	no. of exposures reflown	statoscope investigation		
	date (1969)	time[1)]			reference height H_0 [m]	gross errors	accuracy m_{Stat} [m]
wide-angle, h_{abs} = 4990 m							
1	8.4.	12.09^h	N-S	3	4995		0.94
2	8.4.	12.30	S-N	3	4995	3	1.20
3	8.4.	13.04	N-S	3	4990	1	0.59
4	8.4.	13.30	S-N	5	4965	1	0.79
5	8.4.	13.54	N-S	1	4970	1	0.63
6	8.4.	14.24	S-N	1	5011	1	0.72
7	9.4.	12.54	N-S		5045		0.65
8	12.5.	12.11	S-N	5	5001	2	1.30
9	9.4.	13.18	S-N	1	4965	-[2)]	0.58
10	12.5.	12.34	N-S		5014	1	0.87
11	12.5.	14.07	S-N	1	4960	3	0.91
12	12.5.	13.00	S-N	1	5012	1	1.18
13	12.5.	14.27	N-S	2	4993	2	0.80
14	12.5.	13.21	N-S	4	4989		0.91
15	12.5.	14.47	S-N		4957	1	0.80
				30	4991	17	0.89
super-wide-angle, h_{abs} = 3085 m							
1	10.4.	11.29^h	N-S		3077	1	1.08
2	10.4.	11.50	S-N		3064	2	1.12
3	10.4.	12.12	N-S		3043		0.26
4	10.4.	12.33	S-N		3040		0.30
5	10.4.	12.54	N-S		3005		0.31
6	10.4.	13.16	S-N		3028		0.27
7	10.4.	13.36	N-S		3029		0.79
8	10.4.	13.58	S-N		3015		1.16
9	26.4.	11.40	N-S	1	3155	3	1.30
10	26.4.	12.00	S-N		3121		1.10
11	26.4.	12.20	N-S		3095		0.67
12	26.4.	12.40	S-N		3136		0.82
13	26.4.	12.58	N-S		3172		0.47
14	26.4.	13.17	S-N	2	3113		0.44
15	26.4.	13.36	N-S		3121		0.34
				3	3081	6	0.79

1) The times indicated refer to the first exposure of a strip.
2) Change of the reference height for the last 5 registrations by -28 m.

3. COMBINED BLOCK-ADJUSTMENT WITH STATOSCOPE DATA

3.1 - The method: In the second part of the investigation the original statoscope data are introduced into combined adjustment with the photogrammetric block, using minimum height control. Comparison with check points allows estimation of the resulting vertical accuracy.

The version S (statoscope) of the Stuttgart computer program PAT-M-43 for block adjustment with independent models has been used. It allows introduction of statoscope-data or APR-profiles (apart from level conditions of shore-lines) into the combined simultaneous adjustment. The method and the program have been described in |6|. It is expected to improve the vertical accuracy of adjusted blocks by extending bridging distances considerably. Adjustment results also allow analysis of corrections v to statoscope data and empirical weight determination.

Statoscope data are used as weighted observations, with the following observational equation for an exposure station i in strip k :

$$V_{ik}^{Stat} = - Z_{ik}^{Stat} - (a_k+b_k x_{ik}) + Z_{ik}^{PC} \qquad (7)$$

The term $(a_k+b_k x_{ik})$ provides a constant shift and a tilt correction of the isobaric surface along the flight line k. a_k, b_k are unknown orientation parameters, to be simultaneously determined by the combined adjustment. The strips k can be subdivided in several separate lines.

The unknown heights Z_{ik}^{PC} of the camera stations ik appear also as unknowns in the photogrammetric block-adjustment. They provide the connection of statoscope- and block-data in the combined adjustment.

3.2 - Results of controlled tests: A number of combined block-adjustments with statoscope data have been performed with the Oberschwaben material. The absolute vertical accuracy after adjustment is obtained from the check points of the test-field. The total research program has not been completed. The available test results are presented in table 2. They refer to 2 blocks of 200 models (one w.a., one s.w.a.), each of 8 strips with 20 % lateral overlap. Bridging distance is varied from 25 models (62.5 km, two chains of vertical control points) to 12.5 models (31 km, three chains) and 8 models (21 km, four chains).

The weights used for the combined adjustment were:

1 for z coordinates of model points and perspective centres; 0.11 = 1/9 for statoscope data; ∞ for terrestrial control; o for check points.

Table 2 : OEEPE statoscope test "Oberschwaben" - Vertical accuracy of combined block-adjustment (independent models + statoscope data)

vertical control	bridg.dist.i (base lengths)		n vert. contr.	n check pts.	n stato-scope	σ_0 vert. adj. [cm]	v_{Stat} [cm]	v_{PC} [cm]	μ_z check pts. [cm]	‰ h
Wide-angle-block Frankfurt										
8 strips, q=20%, 200 models; 1:28.000, h_{rel}=4285 m, h_{abs}=4990 m										
2 chains	25	1)	18	434	180	23	38	12	84	0.20
+ 2 border pts.	25(12.5)	1)	20	432	180	23	38	12	69	0.16
3 chains	12.5	1)	27	425	180	24	39	12	67	0.16
3 chains	12.5	2)	27	425	180	23	36	11	55	0.13
+ 4 border pts.	12.5(6)	1)	31	421	180	24	42	12	58	0.14
4 chains	8	1)	36	416	180	24	41	12	53	0.12
4 chains	8	3)	36	416	180	23	34	11	45	0.10
+ 6 border pts.	8(4)	1)	42	410	180	24	42	12	50	0.12
Super-wide-angle-block The Hague										
8 strips, q=20%, 200 models; 1:28.000, h_{rel}=2380 m, h_{abs}=3085 m										
2 chains	25	1)	18	414	193	21	35	16	58	0.24
+ 2 border pts.	25(12.5)	1)	20	412	193	21	35	16	57	0.24
3 chains	12.5	1)	27	405	193	21	36	16	55	0.23
3 chains	12.5	2)	27	405	193	21	34	16	57	0.24
+ 4 border pts.	12.5(6)	1)	31	401	193	21	37	16	52	0.22
4 chains	8	1)	36	396	193	21	37	16	52	0.22
4 chains	8	3)	36	396	193	21	32	16	53	0.22
+ 6 border pts.	8(4)	1)	42	390	193	21	37	16	52	0.22

1) linear isobaric correction - not subdivided, 62.5 km
2) linear isobaric correction - subdivided, 2 x 31 km
3) linear isobaric correction - subdivided, 3 x 21 km

The symbols of table 2 which need explanation are:

σ_o : standard error of unit weight for the total (vertical) adjustment

$\bar{v}_{Stat}$, $\bar{v}_{PC}$: root mean square means of the adjustment corrections v_{Stat} of the statoscope data and v_{PC} of the z-coordinates of the perspective centres.

μ_z : r.m.s. mean of the residual height errors at check points = accuracy estimate of the adjusted block.

3.3 - Comment on the results: The results of table 2 demonstrate the effectiveness of the combined adjustment. With bridging distances of 25 models (62.5 km) and two additional control points at the open sides of the blocks absolute vertical accuracies of 69 cm (w.a., 0.16 $^o/oo$ h) and 57 cm (s.w.a., 0.24 $^o/oo$ h) have been reached, with photo scale 1 : 28 000. It is worth pointing out that the accuracy of the combined system is by 22 % and 28 % better than of the statoscope alone, if compared with (5).

The use of two additional control points has small effects, mainly by controlling tilts and twists of long strips.

Shortening the bridging distances to 12 and 8 models (31 km, 21 km) improved the accuracies to 58 cm (0.14 $^o/oo$ h) and 50 cm (0.12 $^o/oo$ h) for w.a.
and to 52 cm (0.22 $^o/oo$ h) and 52 cm (0.22 $^o/oo$ h) for s.w.a., respect.

When the accuracy level is reached which the block has without statoscope, no further improvement can be expected. (Without statoscope data the height accuracies for 12.5 (6) and 8 (4) models bridging distance, respectively, are: w.a. 53 cm, 45 cm; s.w.a. 64 cm, 53 cm). For the same reason subdivision of the linear isobaric corrections gave no or only moderate accuracy improvements. Nevertheless, the accuracy of 45 cm / 0.10 $^o/oo$ h of the wide-angle block, when bridging 8 models, is remarkable.

The corrections $\bar{v}_{Stat}$ of the statoscope data, as obtained from the adjustments are of special interest. Their dependence on bridging distance indicates some systematic error effects. Nevertheless, the r.m.s. values of 38 cm (w.a.) and 35 cm (s.w.a.) although only given weight 1/9, confirm again the unexpectedly high accuracy capability of statoscope measurements. The corrections v_{Stat}, when checked closely, do not show marked evidence of systematic error effects, appearing rather random.

The tests will have to be completed before final conclusions are drawn. It is evident, however, that the accuracy capability of statoscope measurements is considerably higher than hitherto believed. Application for medium map scales (up to 1 : 10 000) seems feasible. Statoscope supported block-adjustments are now expected to bridge very long distances and still give vertical control accuracy sufficient for mapping with contour intervals of 10 m, 5 m, 10' and perhaps even 2 m. With regard to reduction of control the statoscope with combined block-adjustment may achieve a similar breakthrough for heights as perimeter control did for planimetry. Additional tests and practical applications have to verify whether the unexpectedly good results of the Oberschwaben statoscope test can be obtained regularly and repeatedly.

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