

Practical Experiences  
with the Kern PMG 2 Zoom Point Transfer Instrument  
and the Kern CPM 1 Comparator Point Marker

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Abstract

Since the 13th ISP Congress in 1976, Kern introduced two new instruments for analytical aerial triangulation: the Kern PMG 2 Zoom Point Transfer Instrument and the Kern CPM 1 Comparator Point Marker, which is a PMG 2 equipped with linear encoders on the left stage, thus forming a combination of a Monocomparator and Point Transfer Instrument for point selection, point marking, stereoscopic transfer and simultaneous recording of the left image coordinates.

A good number of these instruments have been in operation for some time now by various users. In this paper their practical experiences are compiled with regards to operational aspects, cost-effectiveness and accuracies obtained. Test measurements of the Appenweier Block and the Jämijärvi Block which were made on the Kern CPM 1 and computed on the basis of transferred artificial tie points and on the signalized tie points only, give a good idea of the contribution of point transfer to the overall accuracy.

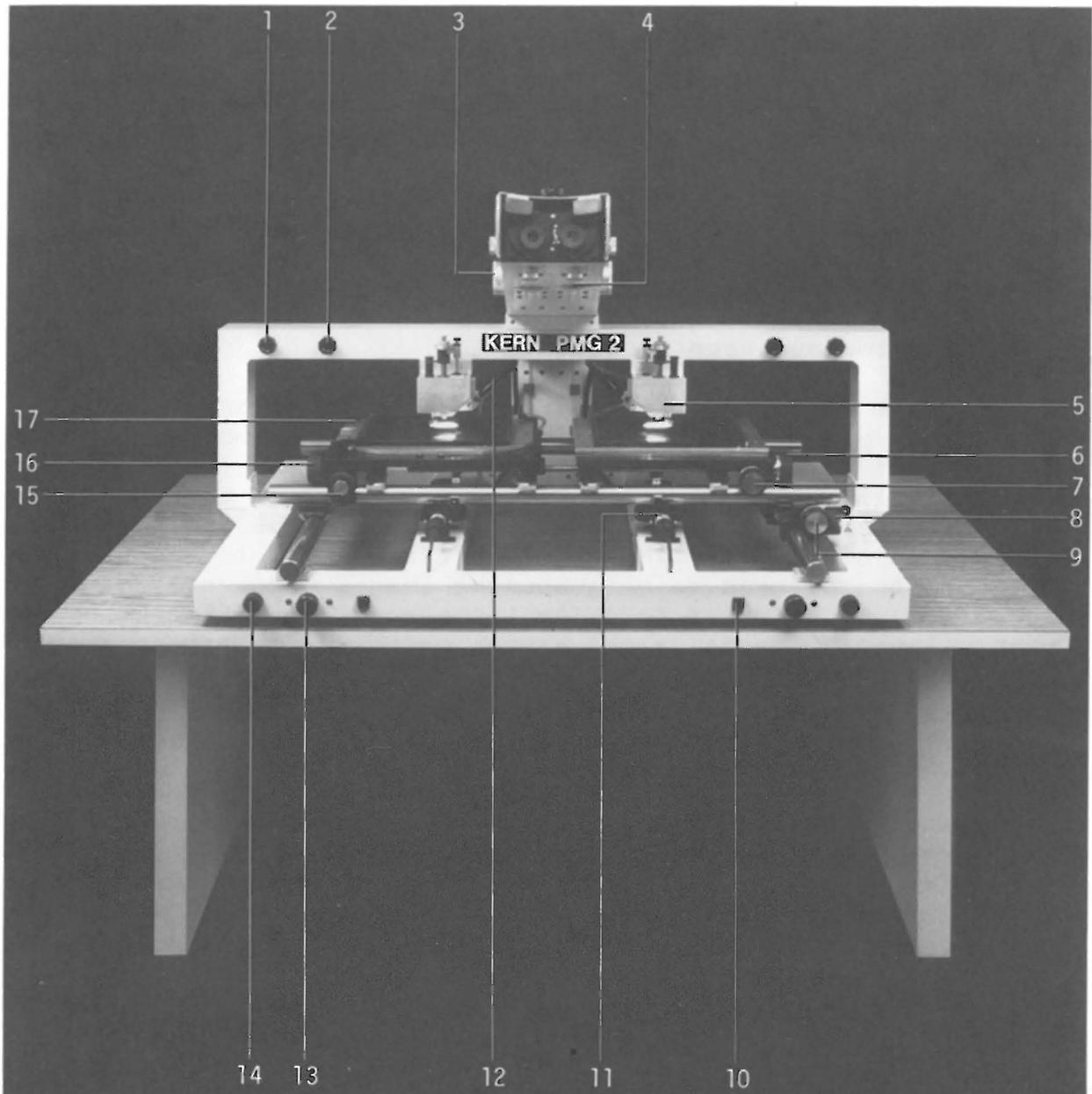


Fig. 1

- |   |                                  |    |  |
|---|----------------------------------|----|--|
| 1 | Drill speed adjustment           | 10 | Start button for right drill           |
| 2 | Drill rate of descent adjustment | 11 | Measuring mark adjustment              |
| 3 | Zoom knob, left image            | 12 | Fibre optics                           |
| 4 | Dove prism control, right image  | 13 | Image illumination adjustment          |
| 5 | Drill spindle head               | 14 | Measuring mark illumination adjustment |
| 6 | $\Delta X$ motion right plate    | 15 | Common X motion clamp                  |
| 7 | $\Delta Y$ motion right plate    | 16 | Common X motion fine setting           |
| 8 | Common Y motion clamp            | 17 | Kappa 1 motion                         |
| 9 | Common Y motion fine setting     |    |  |

## Introduction

The growing use of digital data bases results in higher accuracy requirements for its primary input i.e. ground control and the extension of ground control, be it for mapping projects, engineering surveying, cadastral surveying, or land management. In recent years enormous progress has been made in the field of analytical photogrammetry by the introduction of very sophisticated computing techniques and a good insight has been obtained in the requirements for the control layout as well. The photography itself has been subject to many investigations and the limits seem to have been reached so far.

In control extension, extensive use is made of artificial points which are marked into the emulsion of the images, since in many parts of this world and for many projects it is economically and practically just not feasible to place a large number of targets in the required locations and good natural points are generally not in abundance either. The artificial points are selected marked and transferred to neighbouring images under stereoscopic observation with a point transfer instrument. The call for higher accuracy levels demands also a higher precision in stereoscopic point transfer and requires therefore a point transfer instrument of the highest precision.

Since the 13th ISP Congress in 1976, Kern introduced two new instruments for analytical aerial triangulation: the Kern PMG 2 Zoom Point Transfer Instrument and the Kern CPM 1 Comparator Point Marker which is a PMG 2 equipped with linear encoders on the left stage, thus forming a combination of a Monocomparator and Point Transfer Instrument. The philosophy of the CPM 1 Comparator Point Marker is of course that while the operator has his left measuring mark centered exactly on a point in order to transfer it to the right image, he might as well record its image coordinates at the same time.

In the design of the PMG 2 and the CPM 1 great care was taken to make the instruments operator-friendly, productive, precise and stable [1][2]. Operator-friendliness and productivity are due to the vacuum holddown of the images on the stage plates, the rough relative orientation with  $\Delta y_2$  and Kappa 1, the simultaneous motion of both images on the cross-slide system and superior optics. Precision and stability are due to the overall construction, high precision and stable drill heads, illumination without heat radiation since the light sources are under the table and the light is brought up to the images through fibre optics.

The object of this paper is to report practical experiences of some users of the equipment and to report on two test projects which were undertaken in order to get a good idea of the contribution of stereoscopic point transfer to the overall accuracy of control extension.

### Some practical experiences

A 600 models aerial triangulation project was carried out by North Pacific Aerial Surveys in Anchorage, Alaska. This involved 28 strips at photo scale 1 : 24000 and 10 strips at photo scale 1 : 36000, a total of 38 strips flown with a Zeiss RMK 15/23 camera. Part of the stereoscopic point transfer was carried out with the Kern PMG 2 and another portion was done by another private firm with an existing different make of point transfer instrument. Besides the classical pass and tie points, an additional 10 - 15 points were transferred in each model. Thus, in each model approximately 30 points were transferred. The time with the Kern PMG 2 runs typically 45 minutes per photograph versus 65 minutes on the other point transfer instrument. This gives a production for the Kern PMG 2 of 1 minute 30 seconds per point.

All strips were measured with the Kern MK 2 Monocomparator and computed with a modified (Kennefick) version of the Coast and Geodetic three photo stereo-triplet, strip formation and simultaneous adjustment program. RMS errors in the model ties during strip formation of the portions where the transfer work had been done with the Kern PMG 2 were generally 3 to 5  $\mu\text{m}$  versus 7 to 10  $\mu\text{m}$  for the work done with the other point transfer instrument.

The National Mapping Division of the United States Geological Survey in Reston, Virginia, U.S.A. is using two PMG 2's for point marking and transfer for various purposes. From the operational point of view the superior optics are very much appreciated. The differential zoom range of 5 to 25x is very useful since quite often points are transferred between photographs with scale ratios of 1 : 4 (and a little bit more). In normal transfer work the operators find it easy to recover points and transfer them because apart from the good optics, the rough relative orientation and the simultaneous movement of both plates give greater ease of operation. The fact that the images are held down by vacuum means less handling by hand and this is very important since the emulsion does not get damaged or dirty. The images are used later on in other processes like orthophotoproduction in the GPM 1 Gestalt Photo Mapper, where clean originals are of utmost importance. As a practical means of minimizing the risk of spoiling the emulsion, the images are covered with a thin 0.004" acetate cover and the artificial points are drilled through this cover.

The stability is very much appreciated, adjustment of the relation between measuring mark and drill has to be done once or twice a month only. The absence of heat radiation on the images due to the fibre optics is equally important.

Productivity has increased by 25 % to 33 % since the Kern PMG 2's are in use. For the preparation of the images for the

Gestalt Photo Mapper at least 20 points are marked on each image, these points consist of pass points, horizontal and vertical control points and an additional 10 control points. The production of the Kern PMG 2 in this case is approx. 3 minutes per point.

The images are also used for fully analytical aerial triangulation with the Kern MK 2 Monocomparator. Since the Kern PMG 2's are in operation, the residuals on model ties have come down from 3 - 4 feet (11.4  $\mu$ m - 15.2  $\mu$ m) to 1 - 2 feet (3.8  $\mu$ m - 7.6  $\mu$ m) in planimetry at photo scale 1 : 80000.

The higher accuracy results also in time savings when setting up models in the GPM 1 Gestalt Photo Mapper since the operator sets perfectly on the control points. His confidence level has increased accordingly.

### Test Projects

In order to obtain a good idea about the contribution of point transfer to the overall accuracy of control extension, two test projects were carried out of which the initial results are reported below.

#### The Jämijärvi Test Block

This test area was flown for ISP Commission III, Working Group III/3 "Compensation of Systematic Errors of Image and Model Coordinates" over the test field of the Finnish National Board of Survey, located at Jämijärvi. The test field comprises an area of 2 x 2 sq.km of tree covered ground with 131 precisely signalized geodetic control points. The maximum height difference is about 60 m. The maximum standard error of one coordinate is smaller than  $\pm 5$  mm; the heights have been determined with an inner precision of  $\pm 0.6$  mm/km [3]. The photography consists of 6 strips at 8 to 9 photos giving a total of 51 photographs. Camera: Zeiss RMK 15/23, calibrated focal length: 152.855 mm. Flight height: 600 m. Photo scale: 1 : 4000. Forward and side overlap: 60 %. This test block has so far mainly been used for the project of Working Group III/3 and for testing the accuracy potential of modern bundle block adjustment [4], but of course it lends itself perfectly for an investigation on the accuracy of point transfer. The block can be computed on the basis of the signalized points only and once again on the basis of artificial points only using some signalized points as control points and the other signalized points as check points. The difference in the results gives the contribution of point transfer with the Kern PMG 2 to the overall accuracy.

Diapositives on film material of the Jämijärvi Test Block were put at our disposal by Prof. E. Kilpelä of the Helsinki University

of Technology and five strips involving 43 images were treated by Industrial Forestry Service Ltd., Prince George, B.C. Canada, using their Kern CPM 1 Comparator Point Marker. The image quality of the diapositives is not very good.

The project was treated as a regular production job and carried out under operational conditions as far as stereoscopic point transfer and measurement of image coordinates is concerned. For the computations with their in-house software and computer some extra runs were made.

The procedure employed was as follows: (a) Artificial points were marked and transferred between strips as is normally done, (b) Signalized points were measured and artificial points in a pattern of 5 points across, were measured, marked and transferred at the same time between photos in a single strip. Full use was made of the Dove prisms and the Kappa rotation of the left plate.

Total time spent in preparation of the block for artificial points was about 11 hours, however this included some searching for targets.

A total of 145 artificial points were drilled into the emulsion, 85 strip tie points and 60 internal pass points.

The time spent on selection, stereoscopic transfer and marking of the 85 artificial strip tie points was 6.5 hours.

This means a production of 4 minutes 35 seconds per strip tie point on this photography with tree covered terrain.

The selection, stereoscopic transfer and marking of the 60 internal pass points and the measurement of their image coordinates plus the measurement of 70 signalized tie points and 112 signalized control and check points involving:

(a) Fiducial marks 43 x 4	= 172 measurements
(b) Artificial points	631 measurements
(c) Signalized control points and tie points	722 measurements

giving a total of 1525 measurements  
was executed in 30.5 hours.

This means a production of 1 minute 12 seconds per point (including measurement).

The CPM 1 is a PMG 2 equipped with linear encoders on the left stage, an electronic digitizing unit and recording equipment. The condition for its use as a monocomparator is that the method of "error modelling" is applied. Before a project is started, a very precise grid plate is measured and by means of a computer program supplied by Kern, correction parameters for the removal of systematic instrument errors are determined. With these correction

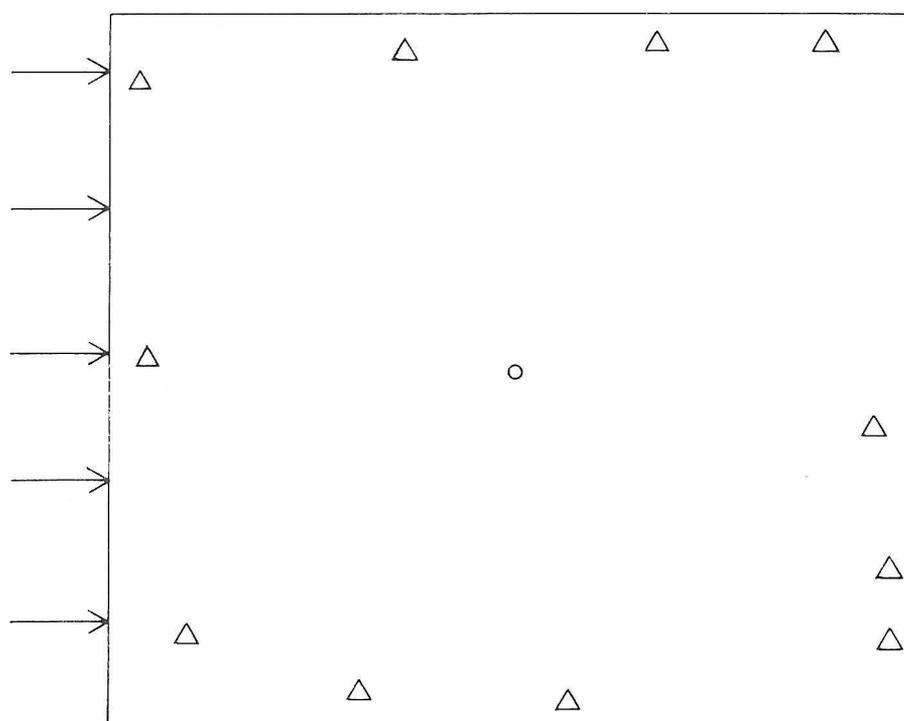
parameters the measured image coordinates are then refined. This was done in this project.

The block was then adjusted in several ways. Initially the block was adjusted using both signalized and artificial points and all available control to identify and isolate any gross errors or doubtful measurements.

With this done two additional "blocks" were derived from the original, one consisting of control- and artificial points only, and one comprised of only signalized points. The latter block was supplemented in several areas by artificial points where targets were lacking or unable to be identified in the tree covered areas.

The blocks were then adjusted in several ways, using the bundle adjustment program by G.H.Schut. The sparse control pattern as shown in fig.2 was used. It consists of 11 horizontal and vertical signalized control points around the perimeter and one additional vertical control point in the center of the block. This leaves 99 signalized points as check points.

Fig. 2 Jämijärvi, general outline of flights and given control points



horizontal and vertical  
△ control points

o vertical control points

Preliminary results:

Table 1:

based on signalized points only

Sparse control	number of check points	r m s						
		residual errors on check points						
		X		Y		Z		
meters	$\mu\text{m}$	meters	$\mu\text{m}$	meters	$\text{‰}$ H			
0 added parameters	99	0.016	4.0	0.031	7.8	0.065	0.11	
6 added parameters	99	0.015	3.8	0.018	4.5	0.036	0.06	

Table 2:

based on artificial points

Sparse control							
		X		Y		Z	
		meters	$\mu\text{m}$	meters	$\mu\text{m}$	meters	$\text{‰}$ H
0 added parameters	99	0.019	4.8	0.031	7.8	0.074	0.12
6 added parameters	99	0.018	4.5	0.018	4.5	0.044	0.07

These results are labelled as preliminary results since this block will also be computed with other types of bundle adjustment programs. The outcome will have to be treated in a later publication.

Comparison of tables 1 and 2 shows that the contribution of the use of artificial points and stereoscopic point transfer to the overall accuracy is in the order of 1  $\mu\text{m}$  at image scale for planimetry and 0.01  $\text{‰}$  H for heights in this test.

The Appenweier Test Block

The Appenweier area is located in the Baden region, in the upper Rhine plains. It covers an area of 9.1 km x 10.4 km = 95 sq.km and contains 24 given trigonometric points of second and third order scattered over the entire area. In order to obtain a sufficient number of vertical control points, 38 points mainly distributed in banks approximately 4 base lengths apart are used. See fig.3. Moreover, the coordinates of 85 check points of roughly regular distribution are known. All control and check points are signalized, the tie points are marked by triple signals for the nine schematic points of an image [5]. The photography consists of 7 strips at 17 photos giving a total of 119 photographs. Forward overlap 60 %, side lap 30 %. Camera: Zeiss RMK A 15/23 wide angle, calibrated focal length 153.22 mm. Flight

height 1200 meters. Image scale 1 : 7800. Flight direction East - West. In this test also diapositives on film material were used. The type of terrain is typical West-European rural area with little forest but many meadows, cultivated fields, roads and small rural settlements. The terrain is relatively flat with height differences in the order of 25 meters.

As a joint project, this investigation on the accuracy of stereoscopic point transfer of artificial points was carried out by the Photogrammetric Institute of the University of Stuttgart, West Germany, on instrumentation made available by Kern & Co.Ltd. For the computations the Stuttgart Bundle Block Adjustment Program was used.

Stereoscopic point transfer and simultaneous measurement of image coordinates was carried out with a Kern CPM 1 Comparator Point Marker. All images were also measured with a Kern MK 2 Monocomparator. Both instruments were equipped with a Kern ER 2 Digitizing Unit with data output on paper tape.

This now enables investigation not only of the accuracy of point transfer, but also of two instrument configurations, Kern PMG 2 - Kern MK 2 and Kern CPM 1, with regard to economics and precision. Although at the time of writing this paper the results are not quite final yet, the operational and economical aspects are treated here and some preliminary results shown. A more extensive report about this investigation will be prepared by Prof. F.Ackermann.

In order to keep to the geometry of all the signalized internal pass and tie points, the artificial points were drilled in their vicinity, also in clusters of 3 points in the nine schematic points for each image. Thus 27 artificial points per image were marked.

First of all, the artificial strip tie points were marked and transferred.

This work consisted of:

- (a) Putting the diapositives on the stage plates and activating the vacuum.
- (b) Rough orientation of both images with  $\Delta x_2$ ,  $\Delta y_2$  and rotation with Dove prism.
- (c) Searching and selection of suitable area for marking of strip tie points.
- (d) Stereoscopic fine setting of the measuring marks and marking of the strip tie points.

A total of 684 points were thus transferred (clusters of 3 points) in 13 hours 25 minutes giving 1 minute 10 seconds per strip tie point. Since clusters of 3 points were used, which makes the process somewhat faster than usual where generally 2 points are taken, a 30 % gain in time could be allowed for

(practical experience value of Stuttgart University) so that in this case the time would be 1 minute 31 seconds per strip tie point.

Then internally in each strip (7 strips) the point selection, point marking, stereoscopic transfer and simultaneous measurement of the left image coordinates was done.

This work consisted of:

- (a) Putting the diapositives on the stage plates and activating the vacuum.
- (b) Rough relative orientation with  $\Delta y_2$  and Kappa 1.
- (c) Searching and selection of suitable area for marking of pass points.
- (d) Stereoscopic fine setting of the measuring marks, marking and transfer of the artificial pass points.
- (e) Measurement of all the image coordinates:

Fiducial marks 119 x 4	= 476 measurements
Artificial pass points (clusters of 3)	3162 measurements
The already marked artificial strip tie points	684 measurements
Signalized control points	300 measurements
Signalized pass and tie points	3087 measurements
Total	7709 measurements

The total time spent on this work was 116 hours, giving a production of the CPM 1 of 54 seconds per point all included.

If we follow the same reasoning as above, by allowing a 30 % gain in time because clusters of 3 points were treated, the production of the CPM 1 would come to 1 minute 10 seconds per point all included.

All the images were also measured with the Kern MK 2 Monocomparator. The total time spent on this work was 74 hours 25 minutes for the same 7709 number of measurements as were carried out with the CPM 1.

This gives a production of the Kern MK 2 of 35 seconds per point.

If we now compare the two instrument configurations Kern PMG 2 - MK 2 and the Kern CPM 1, we come to the following conclusion with regard to the economical aspect:

The transfer of strip tie points will take the same time for both configurations since no actual measurement is involved. So the difference in production time becomes apparent only in the treatment of the individual strips.

If we allow 10 seconds for the actual measurement in the CPM 1 i.e. introducing the point number and code on the input console of the digitizing equipment and pressing the foot pedal for automatic recording, we come to a production of approximately 1 minute

per point for the Kern PMG 2 Zoom Point Transfer Instrument (both for the Jämijärvi test and the Appenweier test).

Configuration Kern PMG 2 - Kern MK 2

Selection, transfer and marking with the Kern PMG 2:	approx. 1 minute per point
Measurement with the Kern MK 2 Monocomparator:	approx. 35 seconds per point
Total time	<u>approx. 1 min 35 sec per point</u>

Kern CPM 1

Selection, transfer, marking and measurement:	approx. 1 min 10 sec per point
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So the time saving with the Kern CPM 1 is approx. 25 %.

The purchase price of a Kern CPM 1 is approximately 70 % of the price of the instrument configuration Kern PMG 2 - Kern MK 2. So, with a capital investment of 70 % and a time saving of 25 % the Kern CPM 1 Comparator Point Marker compares from an economical point of view very favorably with the instrument configuration Kern PMG 2 - Kern MK 2. However, other factors must be also considered when it comes to making a decision about the required instrument configuration for an organisation or for a very large project. In the case of very difficult terrain (featureless, jungle, mountains) or if the yearly workload can not be handled by one operator with one Kern CPM 1 equipped with electronic digitizing and recording equipment or if there is not enough time available to treat an important large project with one Kern CPM 1, the configuration with two or more Kern PMG 2 Zoom Point Transfer Instruments and one MK 2 Monocomparator equipped with electronic digitizing and recording equipment will be a logical choice.

Pending the more extensive report by Prof. Ackermann some preliminary results can be shown, of which conclusions can be drawn only concerning the accuracy of stereoscopic point transfer of artificial points. It must be pointed out that at this stage there is still some uncertainty about the quality of the diapositives on film material which were used in this test. This is still under investigation.

In the initial computations, no "error modelling" was applied i.e. the raw measurements of the Kern CPM 1 were not refined for systematic instrument errors prior to further computations. Instead, 12 additional parameters were used to remove overall systematic errors. In order to keep the computational effort within reasonable limits, the 12 additional parameters were kept invariant for the entire block. For the adjustment all given control points were used, see fig.3.

Preliminary results:

Table 3:  
based on signalized points only.  
Instrument: Kern MK 2 Monocomparator

Number of tie points per image	$\sigma_0$ $\mu\text{m}$	r m s residual errors on check points							
		Number	X		Y		Number	Z	
			meters	$\mu\text{m}$	meters	$\mu\text{m}$		meters	$^{\circ}/\text{oo H}$
27	3.8	73	0.060	8.0	0.045	6.1	57	0.113	0.09

Table 4:  
based on artificial points.  
Instruments: Kern PMG 2 for point transfer,  
Kern MK 2 for measurement.

27	6.2	75	0.066	8.8	0.061	8.0	58	0.120	0.10
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Table 5:  
based on signalized points only.  
Instrument: Kern CPM 1 Comparator Point Marker

27	4.6	68	0.063	8.4	0.059	7.8	51	0.144	0.12
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Table 6:  
based on artificial points.  
Instrument: Kern CPM 1 for transfer and simultaneous measurement

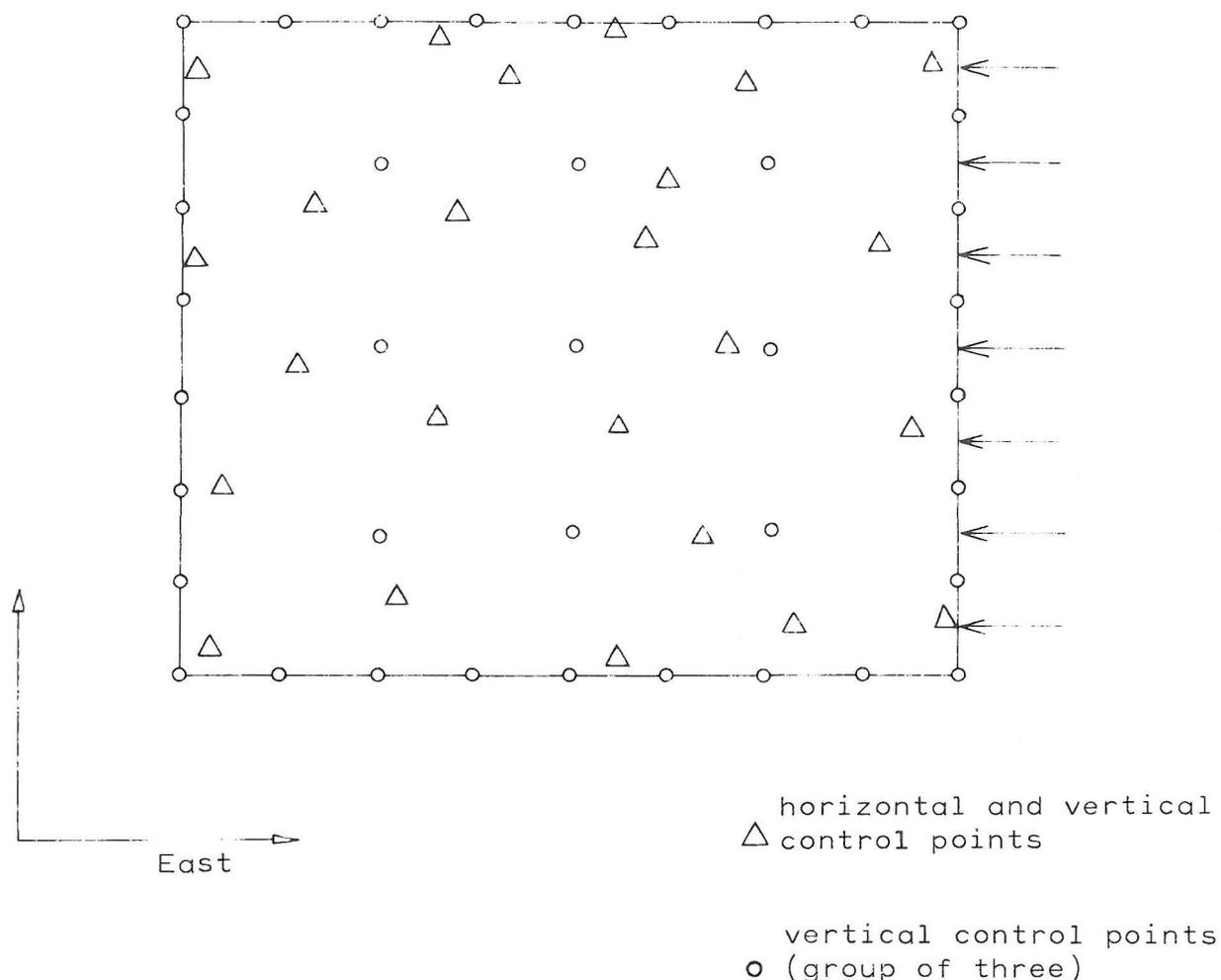
27	6.5	74	0.066	8.8	0.081	10.7	57	0.150	0.13
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The absolute results can not be considered as final yet since further investigations are still carried out concerning "error modelling" and the uncertainty about the quality of the diapositives. In this paper we are concerned with the accuracy of the point transfer only.

Comparison of these preliminary results of table 3 with 4 and of table 5 with 6 shows that the contribution of the use of artificial points and stereoscopic transfer to the overall accuracy is in the order of  $2 \mu\text{m}$  at image scale for planimetry and  $0.01 \text{ }^{\circ}/\text{oo H}$  for heights. The differences in the  $\sigma_0$  values - between  $1.9 \mu\text{m}$  and  $2.4 \mu\text{m}$  confirm this.

The results of the CPM 1 measurements are somewhat less precise than those of the MK 2. A definite comparison concerning the differences in accuracies obtained with these two instruments can not be given at this stage until the investigation in Stuttgart with regard to "error modelling" is fully finished.

Fig. 3 Appenweier, general outline of flights and given control points



### Conclusions

- The new Kern PMG 2 Zoom Point Transfer Instrument allows marking and stereoscopic transfer of artificial points with an extremely high precision and a very high production rate.
- Compared to the use of signaled (ideal) tie and pass points for the extension of ground control, the method of using artificial points drilled into the emulsion and stereoscopically transferred with the Kern PMG 2 or Kern CPM 1 tends to be less precise only by approximately  $2 \mu\text{m}$  at image scale for planimetry and  $0.01 \text{ } \text{‰}$  H for heights.

- The Kern CPM 1 Comparator Point Marker is a very economical tool for point transfer with simultaneous measurement.
- The price of equipment for fully analytical aerial triangulation, be it a configuration Kern PMG 2 - Kern MK 2 or a Kern CPM1 has moved into a range where it becomes imperative even for a small photogrammetric service organisation to add it as an in-house capability, because only fully analytical aerotriangulation gives the solid foundation on which to base further steps in the photogrammetric process.
- The precision of this equipment, coupled with the on-line editing during the measuring stage on the Kern MK 2, Kern CPM 1 and DSR 1 which is in preparation, will greatly increase the confidence level of the operator.

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Professor F. Ackermann and his staff of the Photogrammetric Institute of Stuttgart University for arranging, computing and evaluating the test of the Appenweier Block.

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