Photogrammetric Week'93 Eds. D. Fritsch / D. Hobbie, Wichmann, Karlsruhe, 1993.

New results from photoflights with GPS

HANS-DIETER ARNOLD, PETER HERMS and RALF SCHROTH, Münster

ABSTRACT

This paper describes the extensive activities during the last two years within the HANSA LUFTBILD group in the field of aerial survey navigation and GPS-supported aerial triangulation. Besides elucidating the components of the system, the main emphasis is given to presenting practical results from the use of GPS-based navigation. Another section of this paper deals with the deployment of kinematic GPS and considers its benefits as well as its drawbacks for an aerial surveying company.

1. INTRODUCTION

HANSA LUFTBILD is a company which for over twenty years now has been involved with the use of electronic aids for aerial survey flight navigation. This, it should be noted, against a background of frequent aerial survey projects abroad where often only inadequate navigation documents are available, for example poor quality and outdated, small-scale map material. The company now deploys no less than 4 navigation systems, based upon GPS navigation receivers (GPS = Global Positioning System), in its survey aircraft which operate worldwide.

At the same time as GPS navigation went into operation with the development of the necessary system technology and satellite availability, the first trials began on the introduction of kinematic GPS to support aerial triangulation (Ackermann (1988)). Both the above-named areas will be dealt with below. To start with, a description of the system configuration is intended to provide an overview of the technology in use.

2. SYSTEM CONFIGURATION

The running of everyday aerial survey operations at HANSA LUFTBILD would now be unthinkable without the deployment of GPS. GPS is used for flight navigation as well as for determining projection centres.

The company's policy of dealing with navigation and positioning separately in terms of technical equipment has proved sound and will be continued in the future. Experts will immediately notice this just by observing the aircraft which are equipped with two GPS antennas (see figure 1). Figure 2 shows the arrangement of cameras, GPS line navigation and GPS receivers used for positioning.

3. GPS-BASED NAVIGATION

GPS-based navigation has more than fulfilled the hopes that were placed in it. It is only a matter of time before the traditional, visual navigation system will be replaced for good.

Hansa Luftbild now has 4 aircraft equipped with the navigation system CCNS 4 (computer controlled navigation system) - a system which has proved excellent in practice (see Herms (1991) and Grimm (1992)).

As a result of extensive operational use, several specific changes have gradually been implemented in the system which in their daily use have contributed decisively to survey flights of a very high qualitative standard and have helped ensure that they are carried out cost-effectively:

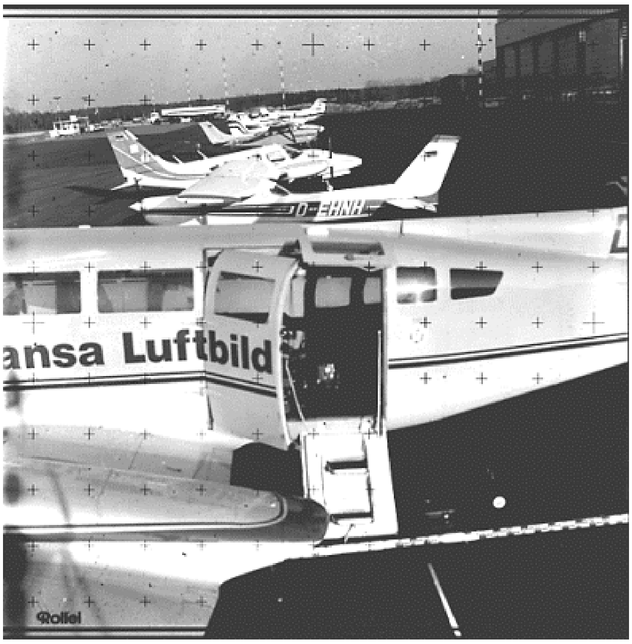

Figure 1: An aircraft using GPS technology.

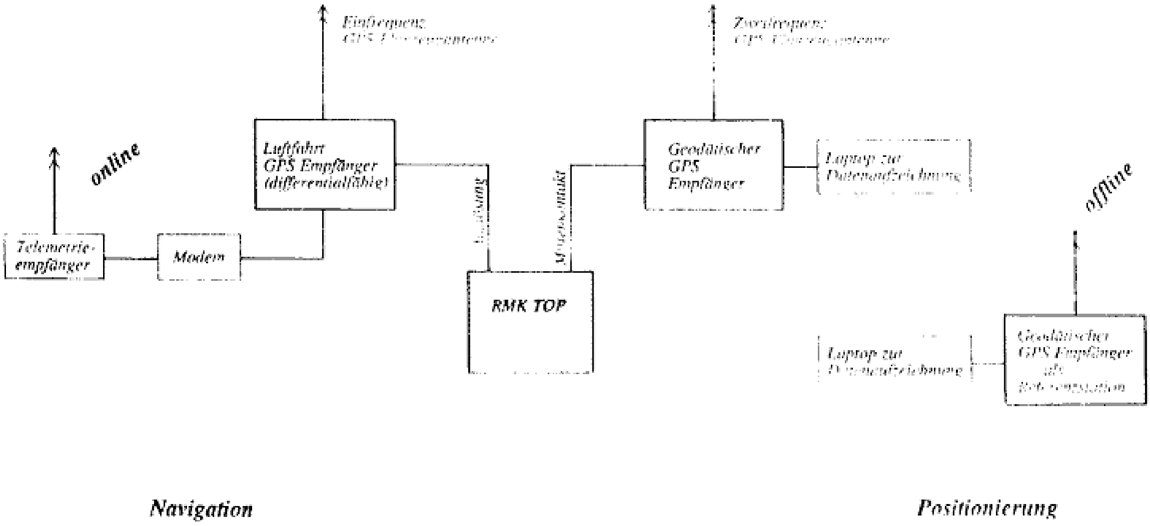

Figure 2: System configuration for GPS navigation and positioning.

3.1 Combining GPS with the directional gyro

The aircraft's course above ground (in international aviation terminology: "TRACK") is calculated from observation of the continually changing GPS position. The directional gyro displays the direction in which the aircraft's nose is pointing (in international terminology: "HEADING"); see figure 3.

The difference between TRACK and HEADING gives the aircraft's drift - an amount needed to ensure that the camera is positioned parallel to the flight path.

Moreover, it was found that the quality of an aerial survey flight is considerably enhanced by the simultaneous display of HEADING and TRACK on the pilot's screen. The pilot thus directly sees

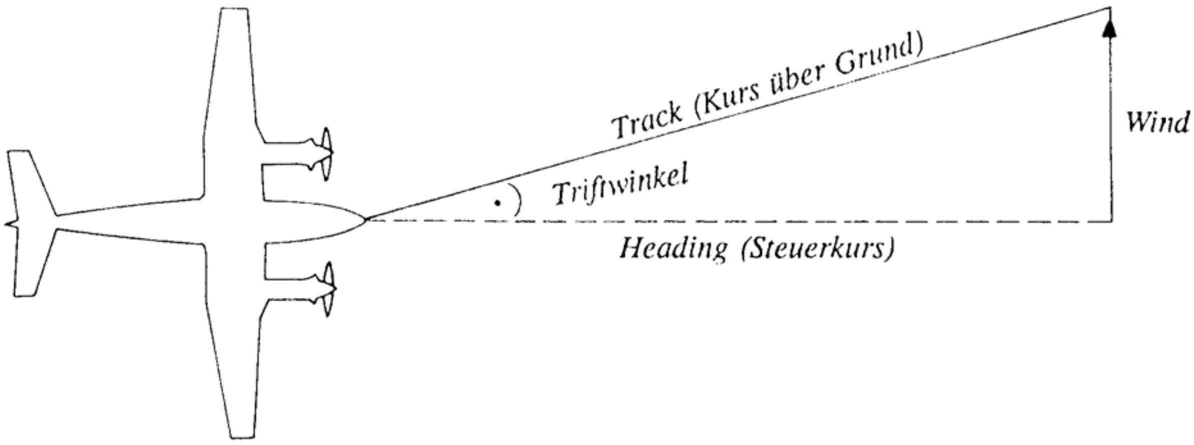

Figure 3: Determining the drift.

the aircraft's "tilt" and hence also that of the camera. In this way he is able to minimise photo tilt or align the photos exactly parallel to a given map sheet.

When information about a change in drift is not available, it is not until a noticeable deviation in TRACK occurs that a corresponding sign is activated which causes the pilot to react. If the wind is very changeable, which is often the case, the result is a very rough flight. However, when HEADING and TRACK are displayed simultaneously, the pilot and autopilot respectively are then able to respond quickly to the slightest change in drift, that is to say, the aircraft need not first drift off its course before a reaction is caused. In this way, the flight is considerably smoother.

3.2 Problems when changing flight lines using GPS systems

An important aspect of achieving cost-effective survey flights is performing turns between flightlines at minimum times. The loss of GPS position during turns may lead to a considerable increase in flying time. The paradoxical situation can then arise that a manually navigated flight can be more cost-effective than one that is GPS-navigated.

In the systems in use at HANSA LUFTBILD, this problem has been solved by using rapid-response receivers (aviation equipment), the processing of altitude information (3 satellites are enough for a 2D position) and by modelling wind. Turns may be initiated immediately after switching off the camera. After straightening up, the aircraft is well positioned overhead the next flight line.

3.3 Kalman filtering supported by gyro information

The process of sequenzing between satellites causes remarkable position changes in the GPS receiver. Moreover it seems that the deterioration of GPS time as caused by SA (selective availability) also causes short period fluctuations in position. The CCNS4 counteracts those effects by Kalman filtering backed up by the properly weighted information of the directional gyro. Firstly, this produces an absolutely steady display for the pilot which on long survey flights enables work to be carried out calmly and without stress - the autopilot can only be used effectively on Remote Sensing flights when the left/right information displayed in this way is this steady!

Secondly, in the course of every day's operational use, it was found out that for line navigation much higher levels of precision could be attained than was theoretically judged possible. Even when SA was switched on uninterrupted navigational accuracy of around 50 m (tolerance) was attained.

Numerous large-scale aerial survey projects, i.e. up to a photo scale of 1:2,500, have been carried out. After taking into account the steering accuracy maintained by the pilot, no deviations exceeding 70 meters occurred.

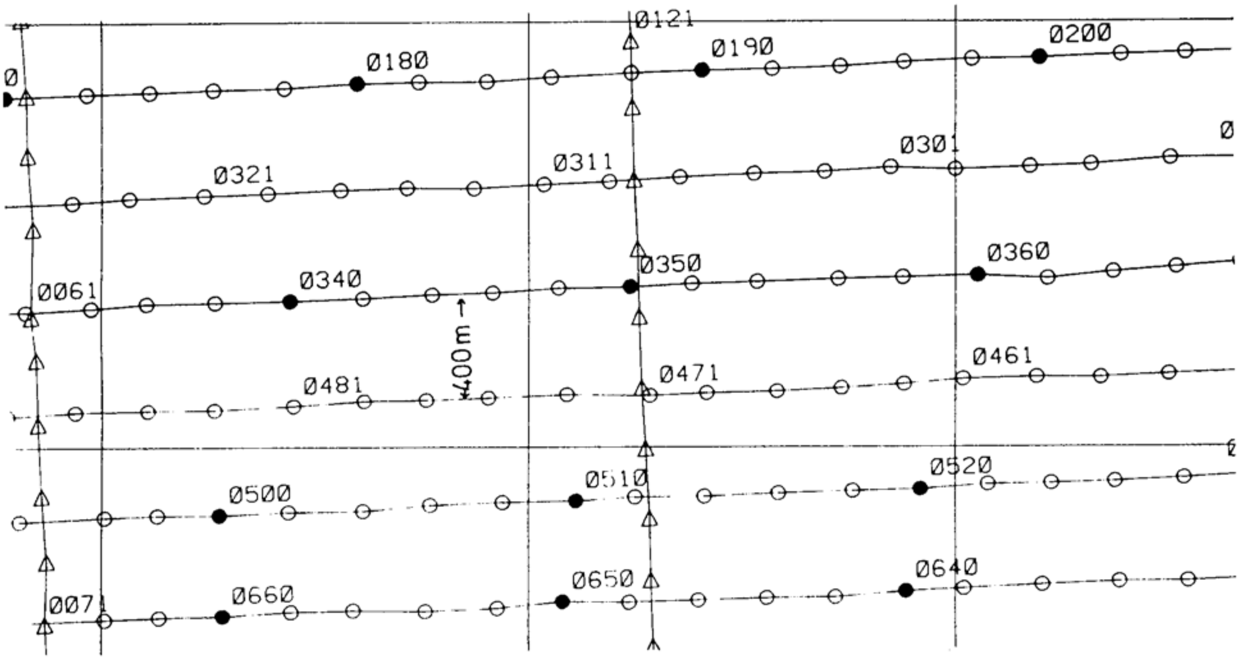

Figure 4: Flight line index.

The previous assumption that the navigation of photo flights at scales larger than 1:8,000 could only be achieved by using online differential GPS has therefore for the time being happily proved not to be the case.

Differential GPS will of course continue to be indispensable for special projects, for example survey flights at very large scales or using laser scanners where a navigational precision of better than 50 m is required. It should be noted here that there are now various radio transmitters which send out corrective signals for differential GPS which can be accessed by anyone. These transmitting stations work in various frequency bands, although interestingly enough the RTCM 104 has clearly established itself as the standard code. In addition to a GPS receiver with a "differential mode", a radio receiver using the appropriate frequency band for the telemetric transmitter as well as a special modem are required in order to convert differential corrective signals.

A discussion of the applications made possible by utilizing these telemetric transmitters for aerial survey technology would however go beyond the scope of this paper.

4. GPS-SUPPORTED AERIAL TRIANGULATION

In contrast to navigation, GPS-supported aerial triangulation is concerned with precisely determining the centre of projection in a 3-dimensional system of coordinates at the precise moment of exposure of a photogrammetric shot. This is achieved with the help of the kinematic GPS process (see Frieß (1990)) in which two precision GPS receivers are used.

HANSA LUFTBILD has been testing this procedure on different projects for more than 3 years now and various receivers have been in use. Evaluations of the results took place at Stuttgart and

Hannover universities and successfully demonstrated the potential of kinematic GPS to support aerial triangulation (see Frieß (1991)).

Below follows a description of the most recent test of GPS-supported aerial triangulation.

4.1 Basic information

The test area covering a length of 220 km and a width of 35 km is situated in an arid region of the Arabian peninsula. Altogether the area was divided into two overlapping sections (B1 and B2) since a total length of 220 km would have meant unacceptable conditions for the subsequent stereo restitution.

The survey flying took place in a Turbo Commander 690 A. The following system equipment was used:

Camera : Zeiss RMK TOP
Navigation : CCNS 4 with GPS (Trimble)
Positioning : 2 GPS Ashtech LXII receivers

The data rate for the simultaneous GPS observation (one receiver in the aircraft, a second on a reference point) was 2 Hz; the maximum distance between reference and aircraft receivers was 120 km.

Evaluation of the GPS data and the calculation of aerial triangulation were carried out by two HANSA LUFTBILD sub-contractors, TopScan Ltd. and INPHO Ltd. in Stuttgart.

4.2 GPS data evaluation

The survey flights for block sections B1 and B2 took place on 24th and 28th October 1992. Ashtech binary data was available for the GPS data. Only C/A-Code pseudo range measurement and the L1-carrier phase observations were used to calculate camera positions.

The GPS observations from both receivers were first decoded, then the phase observations were looked at for gross errors and the inner accuracy of the observations was estimated empirically.

Interruptions in data registration and in signal reception subsequently meant that for 4 photos in all no position could be calculated. The results from the empirical accuracy analysis corresponded to theoretical expectations. Deviations in the carrier phase observations (cycle slips) were brought to light and corrected. Deviations in the GPS trajectories were not found. The inner accuracy (noise) of the GPS coordinates was found empirically to be 0.2 cm for the planimetric coordinates and 0.8 cm for the height (ellipsoidal). Finally, the GPS positions were interpolated with the recorded exposure time.

4.3 Block adjustment

In total the following block parameters were available:

focal length : 153.811 mm
photo scale : 1:50,000
longitudinal overlap : 60%
sidelap : 20%
number of lines : 4
number of tielines : 3

number of photos	:	143 (B2)	136 (B1)
block coverage	:	130 km * 35 km	130 km * 35 km
number of check points	:	63 (B2)	57 (B1)
number of photo points	:	3107 (B2)	2985 (B1)
number of block points	:	623 (B2)	655 (B1)
number of GPS positions	:	142 (B2)	134 (B1)

The Intergraph Intermap Analytic System was used to measure the photo coordinates. The PATB-RS programme with self calibration was applied to calculate block adjustment.
The following a priori standard deviations were used:

photo coordinates	:	Sigma (x,y)	= 0.008 mm
control point coordinates	:	Sigma (X,Y)	= 0.25 m
		Sigma (Z)	= 0.50 m
GPS camera positions	:	Sigma (X,Y,Z)	= 0.10 m

Determining the control points and the check points took place with the help of GPS observations within the scope of a geodetic survey.
All in all, besides a conventional block adjustment two block variations were calculated:

GPS 6VP: GPS-supported bundle block adjustment with 6 control points
(4 lines, 3 tielines)

GPS 4VP: GPS-supported bundle block adjustment with 4 control points
(4 lines, 2 tielines), sub-block B2 only

The block schemas are depicted in figures 5 and 6. For block B1 the GPS 4VP variation could not be ascertained due to interruptions in GPS registration.

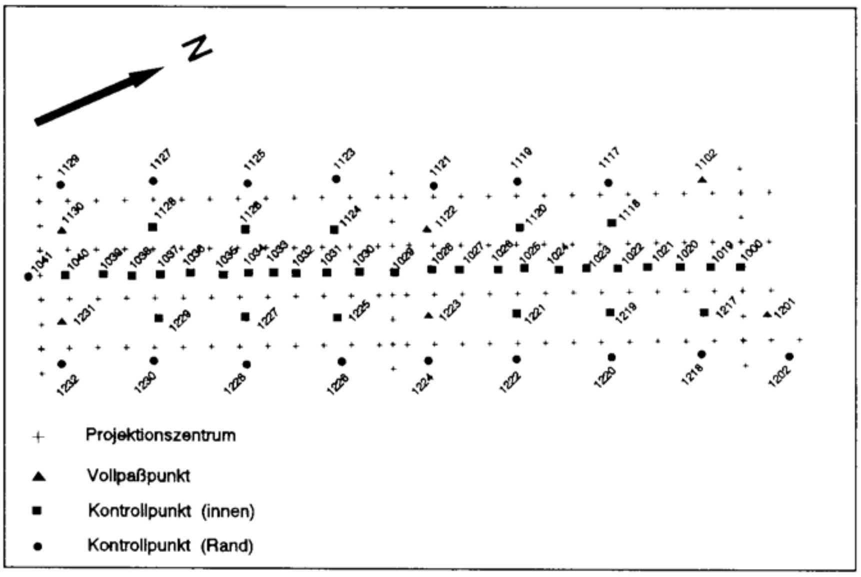

Figure 5: Block schema of sub-area B1.

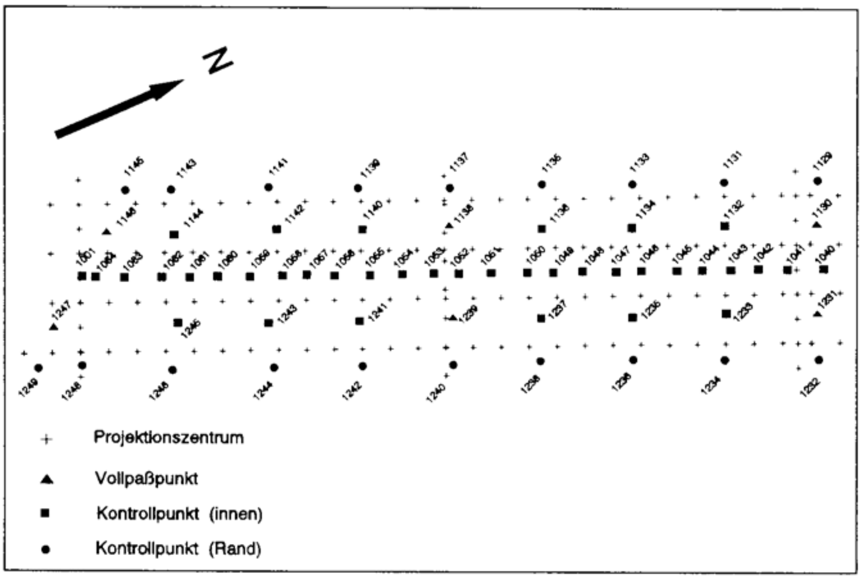

Figure 6: Block schema of sub-area B2.

a) Accuracy of the GPS antenna coordinates

The GPS antenna positions for both blocks were brought as additional observations into the adjustment. On account of the interruptions to the GPS data registration, independent sets of drift parameters had to be introduced. After the adjustment for both blocks the root mean square (r.m.s.) residuals of the antenna coordinates amounted to about 2 cm in planimetry and about 5 cm in height (see table 1). The GPS drift parameters were in all cases accurately set due to the block geometry. These results show that the systematic errors in GPS antenna coordinates are adequately modelled by linear corrections even over longer distances (about 130 km).

Block Variations	Number of Positions	Residues of Antenna Coordinates rmsV(X) [cm]	rmsV(Y) [cm]	rmsV(Z) [cm]
B1 GPS total	134	1.7	2.1	4.4
B1 GPS 6VP	134	1.6	2.0	4.4
B2 GPS total	142	1.9	2.0	5.5
B2 GPS 6VP	142	1.8	2.0	5.2
B2 GPS 4VP	134	1.8	2.0	5.0

Table 1: A posteriori accuracy of GPS antenna coordinates.

b) Empirical accuracy of the GPS-supported block adjustment

The coordinates of unused check points were taken as ideal values (error free) in the empirical analysis of accuracy in the GPS-supported blocks B1 and B2. The empirical accuracy values given (see tables 2 and 3) are based on the comparison of the adjusted coordinates (from the GPS-supported block adjustment) with the coordinates of the check points which were ascertained terrestrially. They include all the systematic "observation errors" which have not been compensated as well as the standard deviations from the check points. Systematic errors which have not been compensated generally turn out to be at points where the block geometry is weakest. This is known to be at the border of the block. The empirical accuracy will therefore be treated separately for points inside the block and for points at the border of the block.

Block Variation	Sigma(0) [mm]	Sigma(0) [cm]	Number of Points	Empirical Block Accuracy rmsV(X) [cm]	rmsV(Y) [cm]	rmsV(Z) [cm]
B1 GPS 6VP	0.007	36.1	34(inside) 17(border)	65.1 69.2	30.7 52.3	69.3 147.7

Table 2: Block B1; empirical accuracy derived from the check points.

Block Variation	Sigma(0) [mm]	Sigma(0) [cm]	Number of Points	Empirical Block Accuracy rmsV(X) [cm]	rmsV(Y) [cm]	rmsV(Z) [cm]
B2 GPS 6VP	0.006	32.7	38(inside) 19(border)	29.6 81.4	25.4 40.2	39.0 87.9
B2 GPS 4VP	0.006	31.6	40(inside) 19(border)	32.0 83.6	34.7 44.9	41.8 102.5

Table 3: Block B2; empirical accuracy derived from the check points.

The empirical accuracy obtained for block B2 is far better than theoretically expected. It amounts to 29.6 cm in X, 25.4 cm in Y and 39.0 in Z for the case using 6 control points and 32.0 cm in X, 34.7 cm in Y and 41.8 cm in Z for the variant with 4 control points.
The empirical accuracy of block B1 is slightly worse compared to block B2. For the check points in the centre of block B1, the quadratic r.m.s. values of differences amount to 65.1 in X, 30.7 in Y and 69.3 in Z. Considered in the absolute, the level of accuracy obtained for a scale of 1:50,000 is judged to be good.
As anticipated, both blocks reveal greater differences between the coordinates compared and their " ideal values" at the border of the blocks. Many of the peripheral points are only simply determined (only measured in 2 photos) as the objective is a topographic/cartographic compilation in which the outer block areas are not included for evaluation. Gross or systematic errors at these points could not be detected.

5. CONCLUDING REMARKS

The application of the Global Positioning System (GPS) for navigation and positioning has proved successful during its first stages of practical implementation. Above all in the area of navigation, it is already possible to speak of a standard procedure. In the field of GPS-supported aerial triangulation, technical problems may often occur due to the multitude of different system components and their incompatibility. A well designed system configuration and thorough checks on it before and after a survey flight is extremely important, because having to repeat a flight due to inadequate data registration means an unnecessary doubling of costs. The element of risk attached to a survey flight is thus inevitably increased. One of the essential preconditions is that staff and the company as a whole possess the necessary experience needed to utilize this new technology.

Additional costs involved in GPS-supported aerial triangulation result from running and organising reference stations on the ground. Many of these stations will at least in the near future be run directly by the clients for whom the survey flights are carried out. However, aerial survey companies are faced with the problem of receiver compatibility due to the vast variety of receiver systems. The company must either have different types of receiver available for survey aircraft (high costs) or limit itself to a specific customer base. The most cost-effective solution is in this case, if the company involved jointly runs both, the reference stations and the station where aircraft are based, given that the distance to the reference receiver had no significant influence on the results of the test flight (about 120 km) described here.

In the future the use of GPS-supported aerial triangulation will thus be determined by a series of external factors. The quality of results and the ability to implement the system technically are today no longer in doubt.

6. REFERENCES

Ackermann, F. (1988): Combined Adjustment of Airborne Navigation Data and Photogrammetric Blocks. ISPRS Congress, Comm. III, Kyoto.

Frieß, P. (1990): Kinematische Positionsbestimmung für die Aerotriangulation mit dem NAVSTAR Global Positioning System. DGK Series C, No. 359.

Frieß, P. (1991): GPS supported aerial triangulation - empirical results. 2nd International Workshop High Precision Navigation, Freudenstadt.

Grimm, A. (1992): Navigation and Positioning for Remote Sensing Flights. ISPRS Congress, Comm. I, Washington.

Herms, P. (1991): Einsatz von CCNS/GPS und RMK TOP - Neue Erfahrungen und Überlegungen zur Bildflugnavigation. Photogrammetric Week, Stuttgart.