Photogrammetrische Woche 1985
Institut für Photogrammetrie
Schriftenreihe, Heft 11, 1986

PRECISION AIRCRAFT GUIDANCE IN ANTARCTICA

F.-J. Heimes, Bochum

1. Introduction

In late summer 1984, the company IGI-Hilchenbach*) was contracted - after an internationally advertised competition - by the Federal Institute for Geoscience and Natural Resources (BGR) to apply the CCNS - Computer Controlled Navigation System for geophysical surveying in Antarctica.

During the south polar summer 1984/85 the BGR carried out the Antarctic Expedition GANOVEX IV (German Antarctic North Victoria Land Expedition). One essential activity of this expedition has been the aeromagnetic survey of an area of 240 000 km² in North Victoria Land and above the Ross Sea (s. appendix 1). For this the two research aircrafts Polar 2 and Polar 3**), both of the type Dornier DO 288-100, have successfully been operated.

CCNS is a navigation management system developed for optimizing special flight missions in the field of:

- aerial photography
- remote sensing
- maritime patrol/surveillance
- flight and airways inspection
- search and rescue
- geophysical surveying.

During the expedition GANOVEX, CCNS has successfully been operated under the severe conditions of Antarctica.

*) IGI-Hilchenbach Ltd., P. O. Box 1207, D-5912 Hilchenbach
**) Polar 2 is owned by the Alfred-Wegener-Institute for Polar Research
Polar 3 was chartered from the Dornier company.

2. Basic Principle of CCNS

CCNS is based on digital processing of data provided by some kind of positioning sensor. Table 1 gives a general review on CCNS mission performance in relation to different positioning sensors.

In view of the requirements for the aeromagnetic survey mission flights in Antarctica the CCNS had to be based on a local network of portable P-DME beacons. Because of a number of advantages compared to others CCNS was based on the precise ranging system Trident III from Thomson CSF.

The computation of the aircraft's exact position is based on the measurement of slant ranges between the airborne interrogator and a number of groundbased transponder beacons which are placed at known positions within the area of operation. The slant ranges derived from the travel time of (coded) pulses are the input to the CCNS computer. The Trident operates at 1219 MHz, with the consequence that range performance is basically limited to line of sight. One interrogator can communicate with a maximum of 32 different coded transponder beacons, but only a maximum of four slant ranges can be measured at the same time. Beacon selection is performed by the CCNS-computer.

The principle of the CCNS/Trident as applied in Antarctica is illustrated in figure 1.

The CCNS-computer calculates the exact aircraft's planimetric position from the maximum of four (and a minimum of two) slant ranges. From actual position and from the parameters of the selected flight line*), steering information is derived which is presented to the pilot in graphical form on a small CRT-type of display. This enables him to intercept a preselected profile line and to follow it with very high accuracy (s. Figure 2). The CCNS-computer is commanded via the control unit which is a small hand-held-terminal.

*) N. B.: Parameters of all mission flight lines are stored on the CCNS computer cassette. - This cassette is prepared during pre-flight mission planning at a separate micro computer (s. mission planning example in Appendix 3).

	CCNS for SPECIAL MISSIONS		Positioning Sensor		
	Mission Performance	Positioning Accuracy after In-flight Calibration	Sensor Type	Sensor Accuracy	Operation
Ground-resp. Satellite-supported Navigation	- Precise Aircraft Guidance - Pin-Pointed Photography or Other Imaging System Control - Saving Ground Control	0.5 - 5 m	Trident or other P - DME	2 - 10 m	regional, network of portable beacons, slant ranges
		0.5 - 2 m	GPS-Navstar (C/A - Code) plus Inertial Nav.	2 - 25 m	worldwide (from 1988) pseudo-range plus inertial sensing
		2 m	GPS-Navstar (P - Code)	5 m	worldwide(from 1995) pseudo-range
	- Precise Aircraft Guidance - Pin-Pointed Photography or Other Imaging System Control	10 - 15 m	GPS-Navstar (C/A - Code)	25 - 50 m	worldwide (from 1988) pseudo-range
		10 - 50 m	VOR/DME/ TACAN	20 - 400 m	regional, network of fixed beacons, slant ranges
		10 - 50 m	LORAN - C	20 - 400 m	regional, network of fixed beacons, time differences
Airborne Navigation	- Restricted Navigation (Updating necessary)	1500 m per hour	Inertial Nav.	1500 m per hour	worldwide inertial sensing
		150 m per 100 km	Doppler Nav.	1500 m per 100 km	worldwide except polar areas, Doppler sensing plus compass

Table 1: CCNS mission performance in relation to different positioning sensors. For the expedition GANOVEX, CCNS was based on the precise ranging system Trident III.

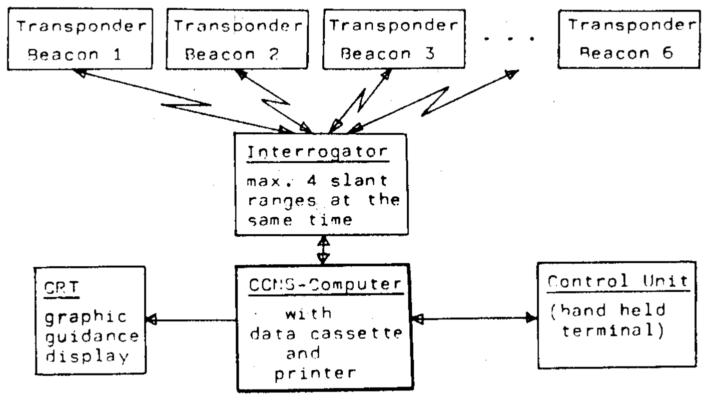


Fig. 1: Principle of CCNS/Trident as applied in Antarctica. Six trisponder ground stations had been installed in the area of operation.

Photogrammetrische Woche 1985
Institut für Photogrammetrie
Schriftenreihe, Heft 11, 1986

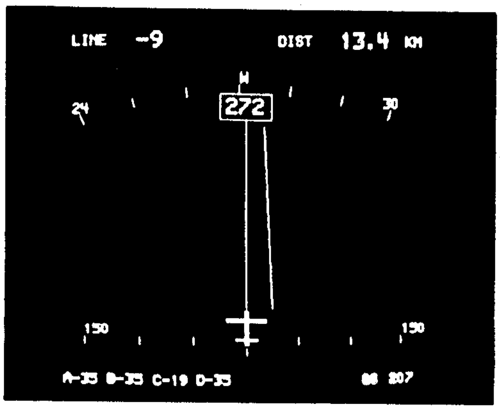


Fig. 2: CRT-graphic guidance display for the pilot. The aircraft follows a "true-track" of 272° and is approx. 25 m left of selected profile line no. 9. Distance (DIST) to the end of line is 13.4 km and the ground speed (GS) is 207 km/h. Four transponder beacons (A, B, C, D) are received with good signal strengths which are displayed in the lower left.

3. <u>Operation and experiences with CCNS/Trident in Antarctica</u>

3.1 Setting up the transponder ground stations

Before the survey flight operations started six transponder ground stations have been installed in the area North Victorialand/Ross Sea (s. Appendix 2). For this Helicopter support was available. Four of the beacons were put at mountains approximately 3 000 m high.

The coordinates of the transponder stations were determined by means of the Doppler Satellite receiver Magnavox MS-1502 with an accuracy between ± 20 and ± 30 m. To set up a station took about two hours, to determine the coordinates took up to seven hours.

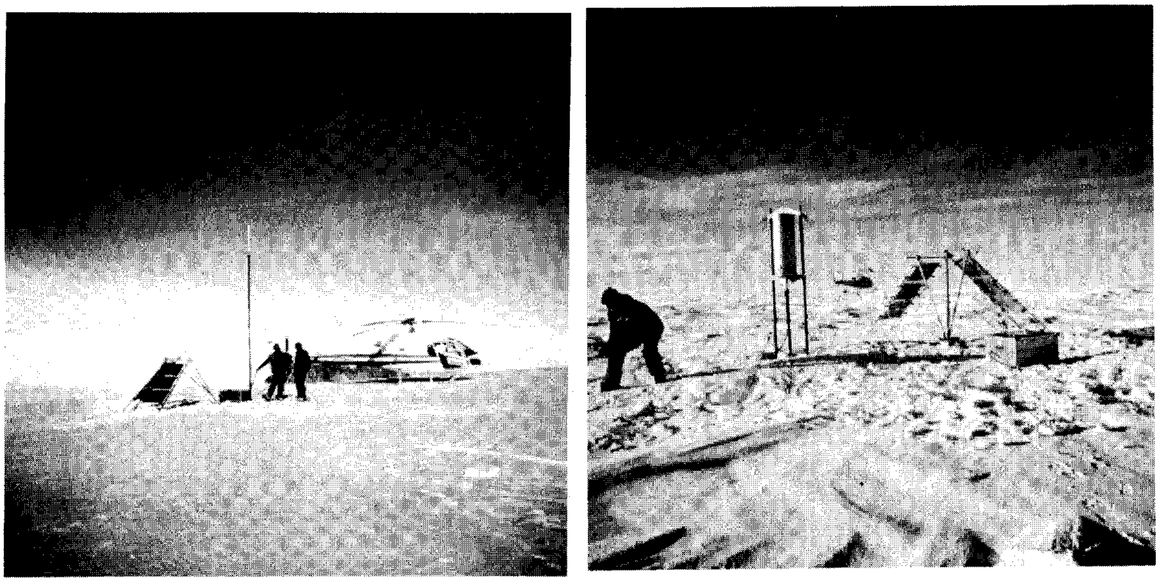


Fig. 3: Transponder ground stations at Frontier Mountain, 2 800 m a.s.l., and at Malta Plateau, 3 000 m a.s.l.. The important components are:

a) the solar panels
b) the box which contains the actual transponder, a battery and the electronic charging control unit
c) the antenna (a 360°-antenna, left; a 200°-directional-antenna, right)

3.2 Performance of the transponder ground stations

On proposal of IGI the beacons were operated by solar energy. When receiving only ("stand-by-mode") the power consumption of a transponder beacon was 17 W, when transmitting (after activation by an interrogator) the power consumption was 43 W. On a clear-sky-day in December the six solar elements of one station produced a capacity of 850 Wh, being enough for 17 transmission hours in one day.

But the weather situation - especially between Christmas and the 13th of January - has been rather variable. Unlike for aerial photography missions, the aeromagnetic survey flights could in most cases be proceeded also under cloudy weather conditions. This and the fact that the mission flights were carried out during the night (because of least magnetic perturbations) has been unfavourable for the beacon power balancy.

A few times it happened therefore that at the station Franklin Island - after a couple of days of heavy cloud cover - the balancing battery was drained; nevertheless after an improvement of the weather conditions beacon operation restarted without problems.

At the stations Mt. Melbourne, 2 700 m, and Malta Plateau, 3 000 m, both situated close to the coast, it occured that with humid air and heavy clouds a strong rime ice formation covered the solar panels to a large extent. At Mt. Melbourne being close to the base camp Gondwana it was possible without very much effort to liberate the solar panels from the strong rime ice cover. For Malta Plateau the rime ice formation was observed on the 8th of January when the flight missions in the northern part were (nearly) finished so that it was not necessary to repair the station.
The stations Mt. Bird, Timber Peak and Frontier Mountain operated from November until January without any problems.

For the mountainous part of the survey area it was not intended originally to apply the CCNS/Trident. Therefore no special care with respect to shading problems was taken when the beacon positions were selected. Nevertheless the Trident performance was such that nearly complete CCNS/Trident control was obtained also above the high mountains.

With the experience gained during the GANOVEX mission two improvements are possible.

The rime ice problem can be overcome by another disposition of the solar panels. The problem of battery drain in case of permanent heavy cloud cover can be overcome (for at least one week) by applying the new Trident IV beacons (12 V, transmission power consumption only 20 W).

IGI is therefore offering now a light weight solar powered beacon station on the basis of the Trident IV which also has the advantage of a data transmission possibility (e. g. meteorological data) from ground to aircraft.

3.3 Flight operations and performance

Both research aircrafts had been equipped with two Trident antennas each, one being at the top of the cockpit the other at the bottom of the rear fuselage. A commutator was switching four times per second from upper to lower antenna and vice versa. This proved to be very favourable because multiple path- as well as shading effects could be reduced efficiently.

The range performance of the Trident has been in very good correspondence with the formula given by Thomson CSF:

$$D = 4.2 \cdot \left(\sqrt{ALT_{(m)}} + \sqrt{Z_{(m)}} \right) \quad (km)$$

whereby: ALT = flight altitude
Z = beacon elevation.

The maximum range obtained was 367.828 km for a flight altitude of 610 m (2 000 ft) and a beacon elevation of 3 000 m (9 850 ft). The computed range for these circumstances equals 334 km.

Because of the selected beacon positions and the given flight altitudes the range performance could be predicted. From this it was obvious that along the eastern edge of the survey area (and at some part of the Ross Sea where the transponder beacon of Malta Plateau was shaded by 2 000 m high Coulman Island) CCNS/Trident operation would be impossible. Here the navigation could be "bridged" by means of the VLF/Omega System. This proved to be better than by means of the Decca Doppler/TANS system, which was aboard both aircrafts as well. Nevertheless it was absolutely necessary to have a CCNS/Trident update before and after those legs (for profiles east-west "bridging time" was approx. 20 mins.: 10 mins outward - 10 mins return). Large areas - especially over the northern Ross Sea and in the north-western part over the iceplateau - have been navigated based on two transponder beacons only.

The decision to use the CCNS/Trident system was taken at a very late date before the start of the expedition. This was the reason why it was impossible to integrate CCNS/Trident into the central data recording unit. Instead every three to five minutes a push button being connected to the central data recording unit and to the CCNS-computer was pressed manually. This resulted in activating a reference counter and in a synchronous print - out of Decca Doppler /TANS positioning data at the central data recording unit and of CCNS/Trident positioning data at the CCNS computer (see appendix 4). The CCNS-computer print out is used during evaluation to correct the less accurate Doppler coordinates.

For the computation of positions from slant ranges plane rectangular coordinates (Lambert II projection) were introduced. The system was chosen in such a way that the profiles were parallel to the X- resp. Y-axis, i. e. for all profiles there was Y = const. resp. X = const. From the CCNS computer print-out therefore the relative (lateral) piloting accuracy can directly be derived. For the example in Appendix 4, profile no. 209, the standard deviation is +/- 41 m.

When the survey operations at the northern part were finished two beacons were moved to the south. Like this it happened that for a great number of position calculations four slant ranges were available. With part of these data a beacon network least squares adjustment was calculated. The standard deviation of the Trident range measurement was found to be ± 9 m. This corresponds to the expectations because the Trident used in Antarctica was modified for extended maximum range performance (theoretical limit 524 km)*).

The accuracy of aircraft positioning not only depends on the accuracy of range measurement but also on the number of ranges from which the position is calculated (max. four, min. two ranges), furthermore it depends on the accuracy of the transponder beacon position coordinates as well as on the geometric configuration for position determination. For the given conditions aircraft positioning accuracy was obtained between +/- 20 m and +/- 40 m.

*) N. B.: Trident range performance normally is limited to 262 km, with a standard deviation of appr. +/- 2.5 m.

4. Conclusions

Only ca. 10 weeks have been available to adapt the CCNS/Trident system for the special requirements of the aeromagnetic mission flights in Antarctica (extended maximum range performance of Trident, solar powered transponder beacon stations, CCNS-computer print-out, special Lambert coordinate system, special mission planning programme).

Nevertheless the CCNS/Trident system has successfully been operated under the "hostile environmental conditions" of Antarctica.

The transponder beacons powered by solar energy performed better than anticipated.

The range performance corresponded to the expectation (more than 300 km, standard deviation ± 9 m).

The accuracy of aircraft positioning was between ± 20 and ± 40 m. Piloting along preselected profiles could be carried out with a relative accuracy of ± 40 m.

Pre-flight mission planning at a separate micro computer and storing the mission parameters on a data cassette proved to be very userfriendly. The principle of defining profile numbers rather than waypoint numbers is very comfortable for in-flight handling.

CCNS software should be improved in two respects. In-flight there should be more flexibility for beacon selection; and stability of track indication at the CRT-display should be maintained also for the case that a (third or fourth) beacon is switching on resp. off.

During the expedition GANOVEX IV 48 000 profile-kilometers of aeromagnetic survey have been covered in total.

N. B.: The expedition ended in a very tragical way when during the return ferry flight Polar 3 was shot down over Westsahara by Polisario people. Three good friends (two pilots, one mechanical engineer) have been killed.

Abstract

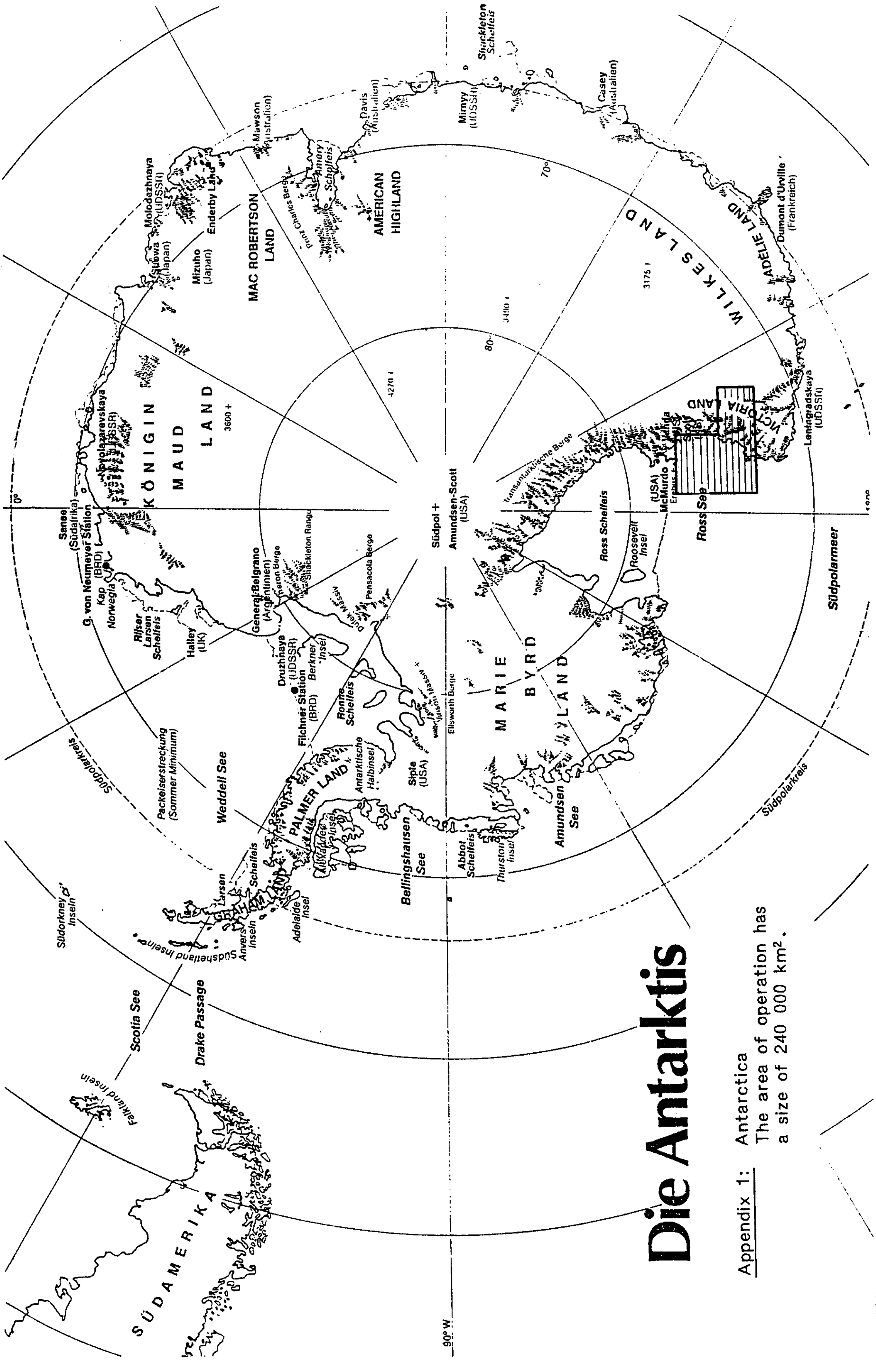
During the Antarctic Expedition GANOVEX IV in polar summer 1984/1985 the CCNS - Computer Controlled Navigation System was applied for aeromagnetic surveys. CCNS being a navigation management system is based on digital processing of data provided by some kind of positioning sensor. CCNS supplies computer supported mission planning, exact steering information for the pilot on a CRT-type of display and can command a camera (or some other sensor) and records position coordinates. For the antarctic mission CCNS was based on the precise ranging system Trident III. In the survey area (240 000 km²) six transponder beacons had been installed, they were powered by solar energy. The CCNS/Trident system has successfully been operated in Antarctica. The range performance was more than 300 km with standard deviation of +/- 9 m. Piloting along preselected profiles could be carried out with a relative accuracy of +/- 40 m. The accuracy of aircraft positioning was between +/- 20 m and +/- 40 m. During the expedition GANOVEX 48 000 profile-kilometers of aeromagnetic survey have been covered in total.

PRÄZISIONS-FLUGFÜHRUNG IN DER ANTARKTIS

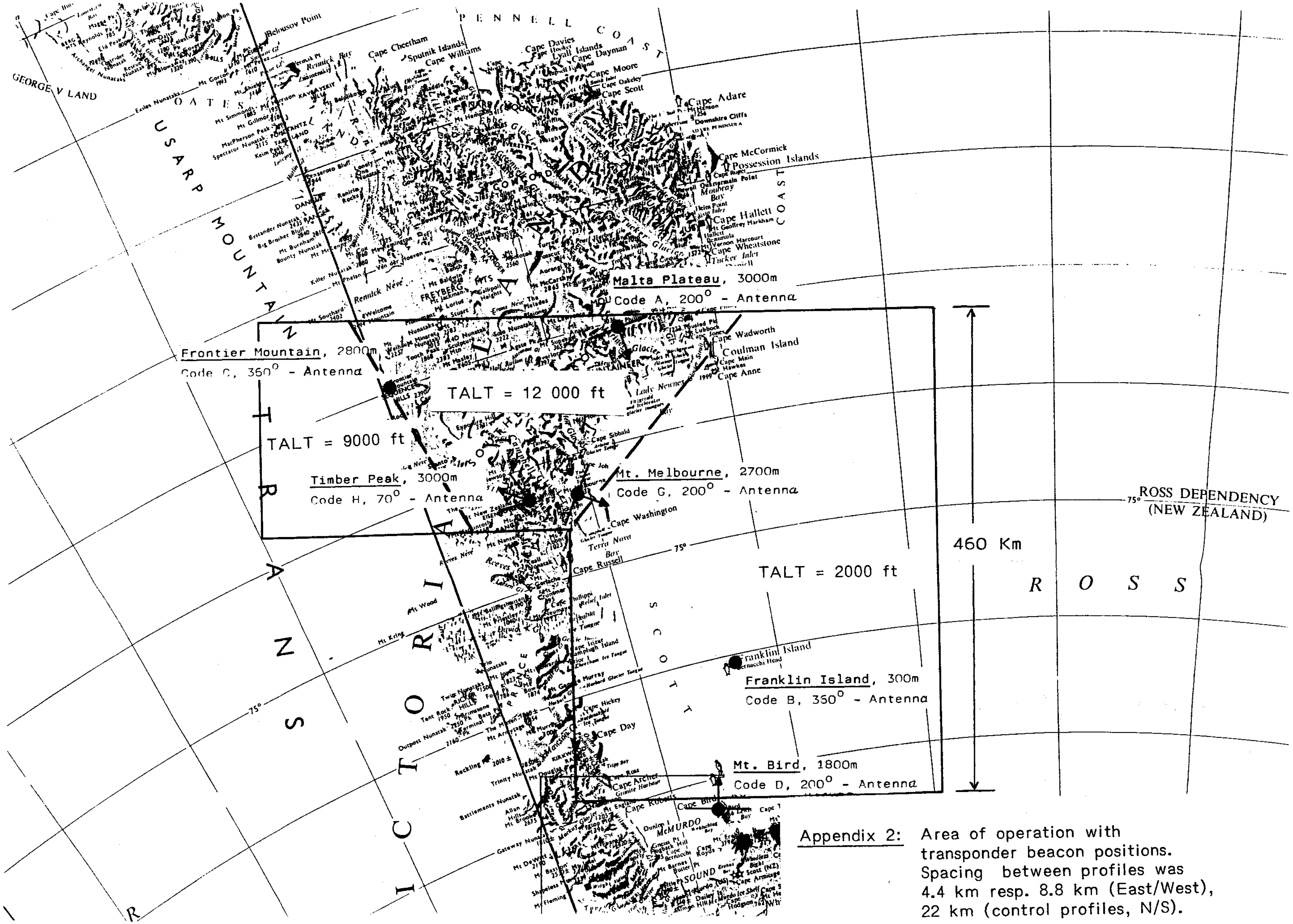
Zusammenfassung

Während der Antarktisexpedition GANOVEX wurde für aeromagnetische Vermessungsflüge das computerkontrollierte Navigationssystem CCNS eingesetzt. Mit CCNS wird vor dem Flug die rechnerunterstützte Flugplanung ausgeführt; im Flug berechnet CCNS die Parameter für die genaue Flugführung. Die Pilotenanzeige erfolgt in graphischer Form auf einem kleinen Monitor. CCNS kann eine Reihenmeßkammer an vorher festgelegten Positionen auslösen (oder kann einen Fernerkundungssensor kontrollieren) und registriert die aktuellen Flugparameter. Bei der Antarktisexpedition GANOVEX war CCNS gekoppelt an das genaue Entfernungsmeßsystem Trident III. Im Operationsgebiet (240 000 km²) waren zunächst sechs Transponderstationen aufgebaut worden, die mit Solarenergie betrieben wurden.

Prof. Dr.-Ing. F.-J. Heimes
Fachhochschule Bochum
Lennershofstr. 140
D-4630 Bochum



Appendix 1: Antarctica
The area of operation has
a size of 240 000 km².



Appendix 2: Area of operation with transponder beacon positions. Spacing between profiles was 4.4 km resp. 8.8 km (East/West), 22 km (control profiles, N/S).

MISSION PLANNING

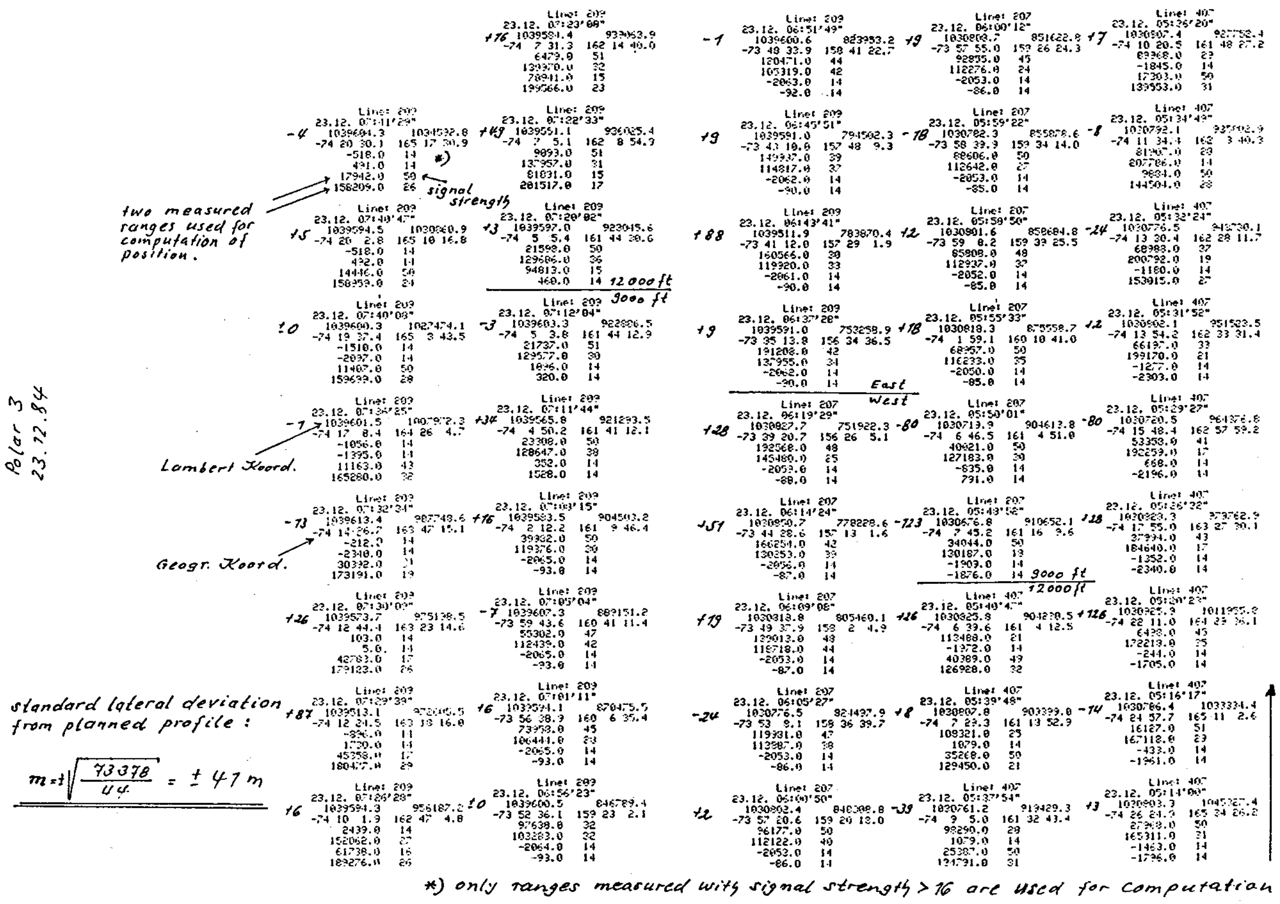
Filename: DBGA   Flight Altitude: 610 m

Beacon	North	East	Elevation
1. D (Mt. Bird)	729 809	1143 928	1788 m
2. B (Franklin Island)	865 257	1160 563	277 m
3. G (Mt. Melbourne)	1034 986	1017 462	2675 m
4. A (Malta Plateau)	1195 667	1064 081	3000 m

Reference Line			Parallel Lines			Number of Lines
No.	Start Point (N) (E)	End Point (N) (E)	L/R	from to	Spacing	
140	736 000 989 000	736 000 1363 000	L	141 245	4400	146
51	714 000 1011 000	1220 000 1011 000	R	52 66	22000	16
			Total Number of Lines 162			

Appendix 3: Example MISSION PLANNING
Mission planning is carried out at a separate micro computer. Parameters of all mission flight lines are stored on cassette which is put into the airborne CCNS-computer. If the flight line pattern is regular the mission planning is very simple. In the example 122 flight lines are defined. In such a case mission planning takes about 20 minutes. Different missions ca be stored on one cassette.

Photogrammetrische Woche 1985
Institut für Photogrammetrie
Schriftenreihe, Heft 11, 1986



Appendix 4: CCNS-Computer Print-out

After pressing the reference push button the following data were printed: line (profile) number, date, time, plane Lambert coordinates, geographical coordinates, measured slant ranges with corresponding signal strengths. The profile no. 209 is along X = const. = 1039 600. The pilot (manual steering) followed the profile with a standard lateral deviation of +/- 41 m.