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Director of Research

FORWARD OBSERVER INSTRUMENT FUNCTIONAL MODEL - USER TRIALS AT ÄLVDALEN, SWEDEN, 12 - 17 NOVEMBER 1998

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b)	Laser rangefinder	b)	Laser avstandsmåler
c)	Fiberoptic gyro compass	c)	Fiberoptisk gyrokompass
d)	Goniometer	d)	Goniometer
e)	Digital magnetic compass	e)	Digitalt magnetkompass

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8) ABSTRACT

This report presents the results of user trials carried out in Älvdalen in Sweden with a functional model of a forward observer instrument.

The modular functional model is made up of a main module developed in co-operation by FFI and Simrad Optronics ASA, a gyro compass with a fiberoptic gyro, developed by FFI, and a goniometer developed by Leica Geosystems AG. The main module includes an eyesafe laser rangefinder, internal digital magnetic compass and internal GPS.

The report includes the results achieved both with handheld operation of the main module with bearing obtained from its built in digital magnetic compass, and with tripod-mounted operation with bearing obtained from the more accurate gyro compass and goniometer. Also the ergonomics of the functional model are discussed.

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FORWARD OBSERVER INSTRUMENT FUNCTIONAL MODEL - USER TRIALS AT ÄLVDALEN, SWEDEN, 12 - 17 NOVEMBER 1998

1 INTRODUCTION

User trials of what was called a "Test Instrument" were carried out at Haslemoen, Norway, in March 1996. The Test Instrument consisted of an eye-safe laser range-finder (LE7 from Simrad Optronics ASA), a digital magnetic compass, and a GPS receiver, and was built in order to test the concept of a hand-held forward observer instrument using a magnetic compass as its azimuth reference. The results from the tests satisfied the user requirements (1). Hence, as part of an FFI (Norwegian Defence Research Establishment) project (Project 697, FA 2000, phase 3, sub-project 2: "Forward Observer Instrument"), the development of a Functional Model was started, as a step towards a production-ready prototype, bearing in mind the Norwegian Army Materiel Command project FP 5014 Forward Observer Instrument.

The Forward Observer Instrument is made up of a "Main Module", developed jointly by FFI and Simrad Optronics ASA, a fibre-optic gyro based north-finder, developed by FFI, and a goniometer developed by Leica Geosystems AG.

Since the commencement of the development of the Functional Model the materiel commands in Norway and Sweden have signed an agreement for joint purchase of a forward observer instrument. In order to carry out laser ranging measurements with shell bursts it was decided that the user trials should be held on the firing range at Älvdalen in Sweden. The trials were held on 12 - 17 November 1998. There were Norwegian participants from the Norwegian Field Artillery School and the Norwegian Army Materiel Command, as well as from FFI and Simrad Optronics ASA. The Swedish participants were from Army Artillery School and Defence Materiel Administration.

Chapter 2 is a short description of the Forward Observer Instrument. The trials programme is summarised in chapter 3, and the results of the Functional Model trials are given in chapter 4. Some ergonomic considerations are discussed in chapter 5, followed by a summary in chapter 6.

This report is a translation of the Norwegian report FFI/RAPPORT-99/02754 and the authors wish to thank Robert Palmstrøm for translating most of the report in a short time frame.

2 DESCRIPTION OF THE FORWARD OBSERVER INSTRUMENT

Figure 2.1 is a picture of the Forward Observer Instrument. We can see the Main Module mounted at the top, the goniometer in the middle, and the north-finder at the bottom, between the legs of the tripod.

The Main Module (called model LP10 by Simrad Optronics) includes a laser range-finder, a digital magnetic compass (DMC), and a GPS receiver. During "normal" use, and when being used for fire control at long range, the Main Module is tripod-mounted, along with the north-finder and goniometer, as shown in the figure. The fibre-optic gyro based north-finder gives the north reference to the goniometer, which in turn supplies the Main Module with its azimuth referred to north. At short range, in situations where a rapid response is required, the intention is that the Main Module will be hand-held, the azimuth being measured by its internal magnetic compass rather than the goniometer.

The instrument user interface is in the Main Module (the goniometer display and keyboard are not used), and the complete instrument is controlled using this interface. Thus the user interface is the same whether the Main Module is hand-held or tripod-mounted (with the north-finder and goniometer). When the operator depresses and releases the laser firing button the range, azimuth and elevation of the target are measured, as well as the instrument's own position, and the Main Module automatically calculates the target's coordinates.

Figure 2.1 Forward Observer Instrument - Functional Model
Top: Main Module (LP10), Middle: Goniometer (SG12), Bottom:North-Finder

2.1 Main Module (LP10)

The Main Module is the central unit of the system. As mentioned above, the Main Module can be used hand-held or tripod-mounted with the north-finder and goniometer when greater accuracy is required. The major components of the Main Module are:

- Eye-safe laser range-finder
- Digital magnetic compass (DMC)
- Internal GPS receiver
- Laser target illuminator
- Operator interface in the form of a miniature VGA display and buttons for menu selection and laser firing
- Telescope with 8× and 15× magnification
- Tilted eyepieces
- Digital interface to the north-finder, goniometer and Multifunctional Terminal (MFT)

The eye-safe laser range-finder is Nd:YAG OPO (optical parametric oscillator) based. The laser transmitter consists of two main parts: A traditional Nd:YAG laser similar to those used in the non-eye-safe laser range-finders already in use in the Norwegian armed forces, and an OPO crystal which converts the non-eye-safe light to an eye-safe wavelength before the light leaves the range-finder.

The digital magnetic compass is the Leica Geosystems AG model DMC-1S. The compass is a three-axis instrument with built-in tilt sensors which determine the orientation of the compass. In the Functional Model one of the tilt sensors is used to determine the elevation of the target.

The GPS receiver is the Rockwell Collins model MPE-1 (Miniature PLGR engine 1). This is a printed circuit board version of the PLGR (Precision Lightweight GPS Receiver) (of which the Norwegian armed forces have purchased a large number) and is thus functionally similar. Both PPS (Precise Positioning Service) and SPS (Standard Positioning Service) versions of the MPE-1 are available. The Main Module can have either PPS or SPS cards installed as required since they both have the same interface.

When the development of the Main Module was started the users required a laser target illuminator as part of the instrument. Since then the requirement for a target illuminator has been dropped. However, by then the optical design, with an internal target illuminator, had been completed, so the Main Module was built with the target illuminator. The target illuminator, which is not the same as a laser designator (which is used for steering bombs), illuminates a spot which can bee seen at a range of several kilometres in darkness with an image intensifier. Swedish officers have on several occasions expressed an interest in using the target illuminator for remote controlled firing of mines. It should be possible to transmit a coded signal with the target illuminator which would trigger a mine as a vehicle passed.

The Main Module operator interface has only a few knobs and buttons for menu selection and laser firing, and a miniature VGA display with 640 × 480 pixels. The display, which is made by Planar, is an AMEL (Active Matrix Electro-Luminescent) display of dimensions 15 × 11 mm. Unlike liquid crystal displays AMEL displays (with an operating temperature range of -40 to 75 °C) operate satisfactorily at low temperatures. According to the manufacturer the display has 32 gray levels, which is somewhat inadequate for displaying video images, however the manufacturer is developing displays with 256 gray levels. In the future it will be possible to show video images from, e.g., an IR camera on the display in the Main Module.

In response to a request from the Norwegian Field Artillery School the telescope has been designed to be switchable between 8 and 15 times magnification. Range-finding can be carried out at both magnifications.

Due to ergonomic considerations the Main Module has tilted eyepieces. The advantages and disadvantages of tilted eyepieces are discussed in section 5.3.

The Main Module has an *RS-232 digital interface* for communication with the north-finder and goniometer. The Main Module has also been prepared for a digital interface with the Multifunctional Terminal (MFT), which is being developed by Thomson Nortec.

2.2 North-Finder

This north-finder is based on a fibre-optic gyro, model FOG 1000/80, developed by the US company Fibersense Technology Corporation. The optical fibre is 1000 m long, wound with a coil diameter of 80 mm (these dimensions giving the model number of the gyro). The north-finder also has an accelerometer which is used to measure the tilt of the gyro input axis while it is finding north. By measuring the tilt of the north-finder (and hence also of the goniometer), and allowing for this tilt, it is not necessary to level the instrument accurately. This reduces the set-up time of the instrument.

After the north-finder has established the direction of north (relative to the common reference axes of the north-finder and goniometer), it is transferred to the goniometer along with the tilt angles. The goniometer in turn supplies the Main Module with azimuth angles referred to north and the horizontal plane.

2.3 Goniometer (SG12)

The goniometer is the Leica Geosystems AG model SG12S. The SG12S was designed with the intention that it should be the central unit, measuring range and position with a laser and external GPS receiver. The goniometer therefore has some functions which are not used in our system, where the Main Module is the central unit. It is supplied with azimuth by the goniometer when it is connected. E.g. the goniometer has a built-in digital magnetic compass of the same type as that fitted in the Main Module, and its own user interface in the form of a liquid crystal display and a keyboard. Neither of these is used in the Functional Model. The reasons we still chose to use the SG12S in the Functional Model were that the goniometer has a digital interface and that Leica were willing to carry out the necessary mechanical and software alterations.

In the SG12 azimuth is measured by an optical encoder with an accuracy (standard deviation) of 1 mil. Elevation in the SG12 is measured by one of the tilt sensors in its compass. According to the specification this has an accuracy (standard deviation) of 3 mils. As the Main Module, as mentioned above, contains the same sensor, in the Functional Model elevation is always measured using the Main Module's tilt sensor. Thus it is purely azimuth that is read out from the goniometer.

A more detailed description of the goniometer is given in reference (2).

3 TRIALS PROGRAMME

The trials were held, as mentioned above, on 12 - 17 November 1998. The daily programmes are summarised below:

Day 1 - Thursday 12.11. 98

<u>IR Imaging - Theory</u>
Celsius Tech Electronics (CTE), represented by Stefan Johansson, gave a review of IR technology, presenting alternative detectors, camera technologies, and range estimates. Parts of the presentation are available as an Excel spreadsheet.

<u>Presentation of the Forward Observer Instrument Functional Model</u>
FFI gave a short presentation and demonstration of the Functional Model, particularly for some Swedish officers who would not be taking part in the trials on the following days.

<u>IR Cameras - Demonstration</u>
In the afternoon the following IR cameras were demonstrated:

- Prototype QWIP (Quantum Well Infrared Photodetector) camera made by AGEMA
- Uncooled prototype camera made by CTE
- BILL-sight, first generation IR camera
- Reference camera based on the British SPRITE detector
- Thermal Weapon Sight (TWS) from Hughes (Raytheon)
- Sentinel uncooled camera from Amber (Raytheon)

The demonstrations gave an impression of the performance of the various cameras, but it is difficult to draw any conclusions from such a demonstration. It was snowing during some of the tests, and yet again we were reminded that IR cameras do not function well in all weathers.

Tests in darkness with artillery firing

In the evening the QWIP camera was used to observe shell impacts in darkness. The IR camera's maximum field of view was (as far as we remember) approximately 6°, and it was difficult to capture the impact in the field of view. Although no impacts were within the field of view while we were looking at the QWIP camera picture, it was claimed that a shell impact was easily seen when that was the case. As well as the QWIP camera, the TWS camera and the Main Module with the Simrad model KN200 Clip-On Image Intensifier were used. The laser target illuminator in the Main Module was also demonstrated. The illuminated spot was visible with image intensifiers at ranges of several kilometres.

Day2 - Friday 13.11.98

Swedish Forward Control Officers' Requirements

A Swedish forward control officer presented their requirements for a new forward observer instrument. A number of requirements were mentioned, including: Low weight, built-in compass, position determination, operation in darkness, good optical quality, data communication, and remote controlled firing of mines. They have identified a need for an improved remote control firing method.

The idea of using the target illuminator in the main module for remote controlled firing sounds interesting. The forward control officers would like an asymmetric laser spot with a suitable height/width ratio. The intention is to track a vehicle with the laser, and as the laser beam passes the mine firing detector the mine is fired. The mine and detector would have to be correctly placed relative to each other, the field of view and road, such that the vehicle is hit. A possible problem with this technique is that a vehicle with a laser warning system could detect that it was being illuminated, and possibly stop in order to try to eliminate the threat.

Presentation of the Forward Observer Instrument Functional Model

FFI presented the Functional Model and its operation in greater detail than on the previous day.

Laser Tests

Tests of the laser range-finder were carried out at Rivsjön on the firing range at Älvdalen. The results are presented in section 4.5.

Day 3 - Saturday 14.11.98

Range-Finding to a Shell Burst

In the morning we travelled to a forward observer's position on a hill called Snoddskallen on the firing range at Älvdalen in order to make measurements to shell bursts. There was some uncertainty as to whether the Functional Model's eye-safe laser would be able to range-find to shell bursts. With shell bursts at a range of approximately 1500 m this proved not to be a problem.

From the same forward observer's position we could see an Artillery Hunting Radar (ARTHUR), and using the laser in the Main Module we measured the distance to the radar as approximately 6500 m. The radar was on a hillside, with a background of snow as seen from the forward observer's position. When the laser hit the snow background, and not the radar, no measurement was obtained. This was because of the low reflectivity of snow at wavelengths around 1.5 μm, which is a typical wavelength for eye-safe laser range-finders.

Telescope Tests

In the afternoon telescope maximum range tests were carried out. The instruments that were used were the Main Module's 8×45/15×45 monocular telescope and a FUJI Meibo 15×80 binocular telescope. Given the size and weight of the FUJI binoculars, they were naturally in a different class from the telescope in the Main Module, but the FUJI binoculars were used as a reference.

With the FUJI binoculars one could see a private car on a bridge 8400 m away. With the Main Module telescope at 15 times magnification it was difficult, but not impossible, to see the car. With the telescope set to 8 times magnification the car could not be seen. During the tests it was slightly hazy, with a visibility estimated at 12-13 km.

Day 4 - Sunday 15.11.98

Azimuth Measurement with the Magnetic Compass

The whole day was used for azimuth measurements with the magnetic compass in the Main Module. The results from the tests with the magnetic compass are described in section 4.2.

Towards the end of the tests the laser range-finder ceased to work, without that affecting the azimuth measurements. The reason the laser stopped working was that a high voltage trigger capacitor had failed.

Tests in Darkness

Tests were carried out in darkness using the Main Module with the Simrad KN200 Clip-On Image Intensifier fitted, as well as with the TWS and Sentinel IR cameras mentioned earlier. The tests were carried out on an air strip which was approximately 1 km long. At this range detecting a vehicle with the IR cameras was straightforward. With the Main Module's Clip-On Image Intensifier detection was dependent on having a good contrast between the vehicle and the background. The Main Module's target illuminator was also tried, and it was easily visible at the relevant range, both with the KN200 and with image intensifier goggles. The visibility was good during these tests. The light level was not measured.

Day 5 - Monday 16.11.98

Azimuth Measurement with the North-Finder

In the morning the Functional Model's north-finder was used to find north. The results of these north finding tests are described in section 4.3.

Azimuth Measurement with the Magnetic Compass

Due to problems with the calibration of the magnetic compass on the day before (described in section 4.2.3), further tests with the magnetic compass were carried out in the afternoon.

Instrument Ergonomics Tests

After the two sets of azimuth measurement tests some tests of the instrument ergonomics were carried out. The ergonomics of the instrument are discussed in chapter 5.

Day 6 - Tuesday 17.11.98

The intention had been to use this day for GPS tests. However, because of a lack of permission to use military GPS in Sweden the GPS tests were cancelled. In the morning, however, some measurements of the time used to level the Forward Observer Instrument were carried out. By measuring the tilt of the instrument, as we do with the Functional Model, time is saved since the operator does not need to level the instrument. In order to obtain an estimate of how long it takes to level the instrument we measured the time an operator used to level a theodolite (the reason a theodolite was used is that the Functional Model is not fitted with a levelling mechanism). We measured the time taken to level the theodolite as approximately 30 seconds.

4 RESULTS

4.1 Alternative Methods of Operation (Alternative Aiming Methods)

During the trials the instrument was used in the following ways (see figure 4.1):

- Hand-held, with the operator standing (Main Module only, with azimuth determined by its magnetic compass)
- Hand-held, with the operator sitting (Main Module only, with azimuth determined by its magnetic compass)
- Tripod-mounted (with azimuth determined by the Main Module magnetic compass)
- Tripod-mounted (with azimuth determined by the north-finder and the goniometer)

Figure 4.1 Alternative Methods of Operation: Hand-held standing, hand-held sitting and tripod mounted

4.2 Azimuth Measurement with the Digital Magnetic Compass

4.2.1 Calibration of the Magnetic Compass

The object of calibrating a magnetic compass is to reduce the effects of static magnetic fields with a constant orientation relative to the compass as far as possible. Such fields can be magnetic fields within the instrument itself (e.g. from electric currents, or from magnetic materials in the batteries), and magnetic fields from equipment carried by the operator.

Magnetic disturbances can be divided into two types:

- Hard magnetic disturbances (due to magnets and electric currents)
- Soft magnetic disturbances (due to magnetic materials (e.g. iron))

Hard magnetic disturbances are thus due to sources which themselves have a magnetic field, while soft magnetic disturbances are due to materials which alter an existing magnetic field. The digital magnetic compass has built-in routines for hard and soft magnetic calibration. A 4-point calibration procedure is used for hard magnetic calibration, but soft magnetic calibration requires a more complex measurement geometry, and is implemented by a 12-point calibration procedure. This procedure, however, gives hard magnetic calibration as well as soft magnetic calibration. According to the documentation describing the compass the 4-point calibration algorithm is of low to medium complexity, and only a few seconds are required to calculate the calibration data on completion of the calibration procedure. The 12-point calibration algorithm, however, is more complex, and in the current compass (model DMC-1S) it typically takes approximately 1 minute.

During the tests the time required for the two calibration procedures was measured, giving the following time consumptions:

- 4-point (hard magnetic) calibration: approximately 30 s
- 12-point (soft magnetic) calibration: approximately 4 min (calibration procedure: 3 min, calculation: 1 min)

The magnetic properties of the batteries were an important consideration during the development of the Main Module. Ideally the batteries should be non-magnetic. In practice it was a matter of selecting batteries with a low enough magnetic signature that it was unnecessary to recalibrate the instrument on changing the batteries.

The batteries we chose (units with 2 Li D-cells from Electrochem), however, proved unable to deliver enough current during the Main Module's switch-on phase. During the user trials we therefore had to use the secondary batteries we had used during the laboratory tests. These batteries (Li-ion prototypes from Electrochem), however, have a magnetic signature that requires recalibration on changing the batteries.

4.2.2 Magnetic Declination

During user trials it is undesirable if the local declination influences the measured results. The local declination was therefore entered into the instrument. This was achieved by ensuring that the compass reading when aiming towards one of the aiming points (aiming point 8) equalled the previously measured reference direction.

In addition to the magnetic declination varying with position, it also varies with time. This variation is due to variation in the particle radiation from the sun. During periods of high solar activity the variation in declination can be quite high. At Lahaugmoen, outside Oslo, Norway, the temporal variation in magnetic declination is continuously recorded. However, although the time varying component of the declination does not vary much with distance, the distance from Lahaugmoen to Älvdalen is a bit too large for the data from Lahaugmoen to be used to correct the measurements at Älvdalen. The magnetic field measurements at Lahaugmoen can, however, still be used to determine whether one should expect small or large temporal variation in declination during the measurement period at Älvdalen. Figure 4.2 shows the variation in declination during the measurement period (12:40 - 13:25) on 16 November 1998.

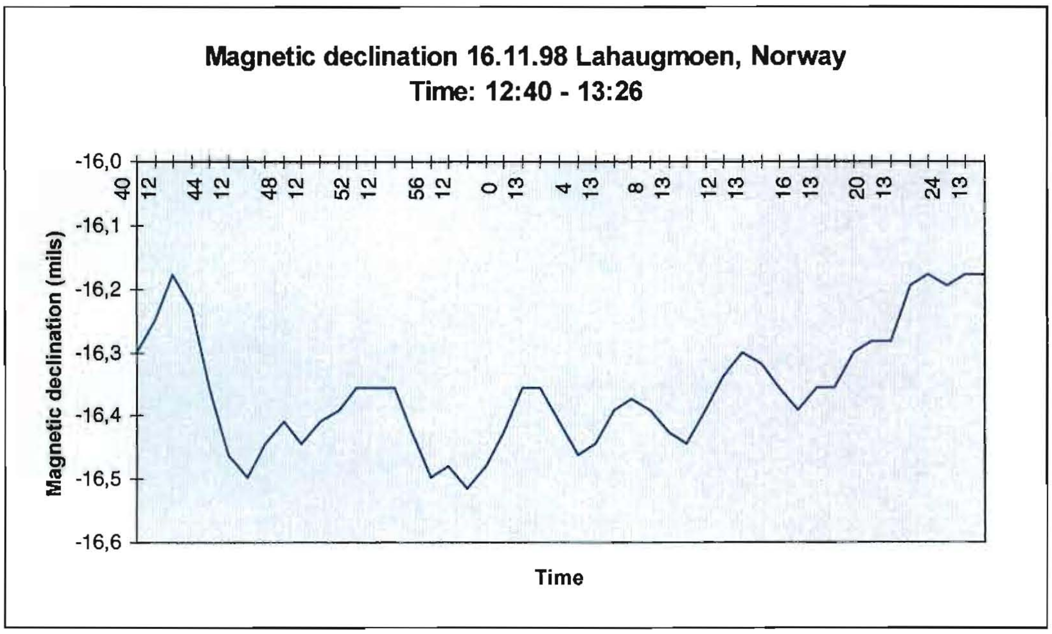

Figure 4.2 Magnetic declination at Lahaugmoen during the measurement period 16 November

As we can see in the figure, the variation in declination, at less than 0.4 mils, was very small during that measurement period.

4.2.3 Average Azimuth Error

As mentioned above, it was originally intended that non-magnetic batteries would be used during the measurements. However, since these proved unable to deliver enough current, we had to use rechargeable Li-ion batteries with a significant magnetic signature.

We had intended to perform an initial 12-point calibration, followed by a 4-point calibration on each change of batteries. We had not carried out enough tests to be sure that a 4-point calibration on changing batteries would give sufficient accuracy, but we reckoned that in field use it would be too time consuming to carry out a 12-point calibration on each change of batteries.

It turned out, however, that the 12-point calibration procedure failed to work due to a software bug in the Main Module. Therefore we first had to limit ourselves to 4-point calibration only without an initial 12-point calibration. As can be seen below, this lead to significant errors.

4.2.3.1 Average Azimuth Error Without 12-Point Calibration

Measurements were carried out with the Main Module hand-held, and the operator both standing and sitting, both with and without webbing, and both with and without an internal battery in the Main Module. Figure 4.3 shows the average azimuth error with the operator standing. Figures 4.4 to 4.6 show the average azimuth error with the operator sitting with and without webbing, and with and without an internal battery, while figure 4.7 shows the equivalent error with the Main Module tripod-mounted.

Only a 4-point calibration was carried out prior to the measurements, since the 12-point calibration failed to work. As can be seen in the figures, the maximum average azimuth error is as large as 91.9 mils, and although the azimuth error with and without webbing does vary, the uncertainty is too large for us to be able to say to what extent the webbing will reduce azimuth accuracy when using the magnetic compass.

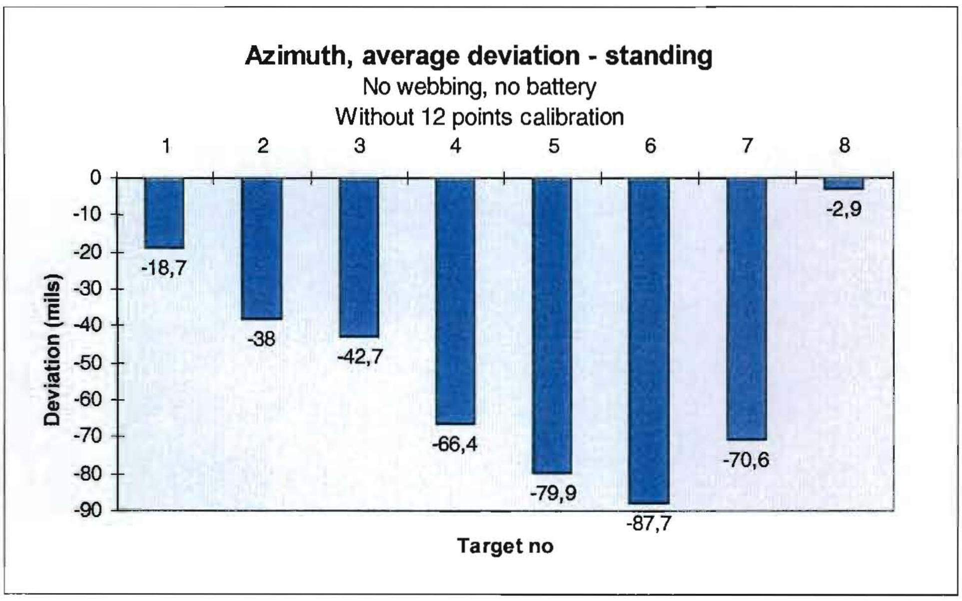

Figure 4.3 Azimuth, standing, no webbing, without 12-point calibration. Each bar represents the average of 5 measurements.

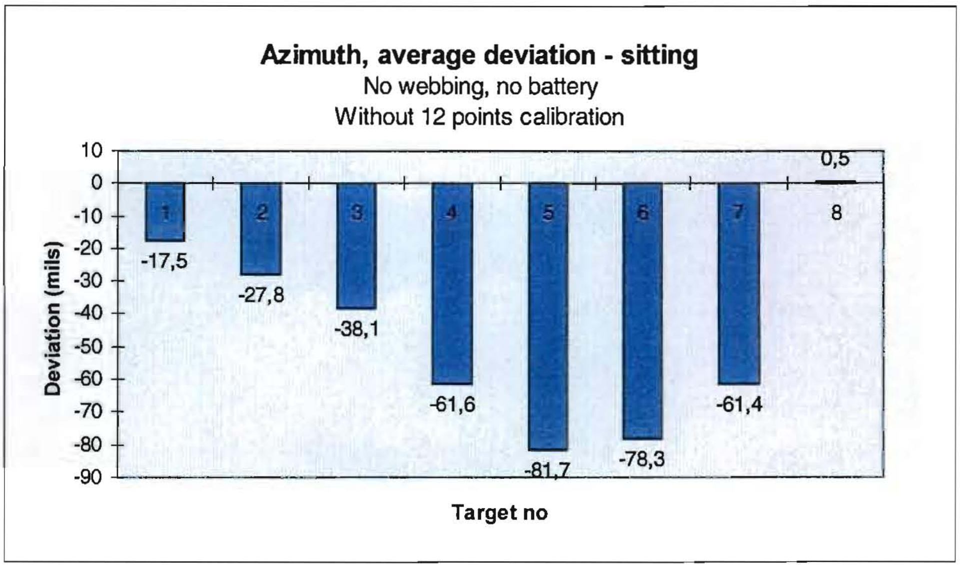

Figure 4.4 Azimuth, sitting, no webbing, without 12-point calibration. Each bar represents the average of 5 measurements.

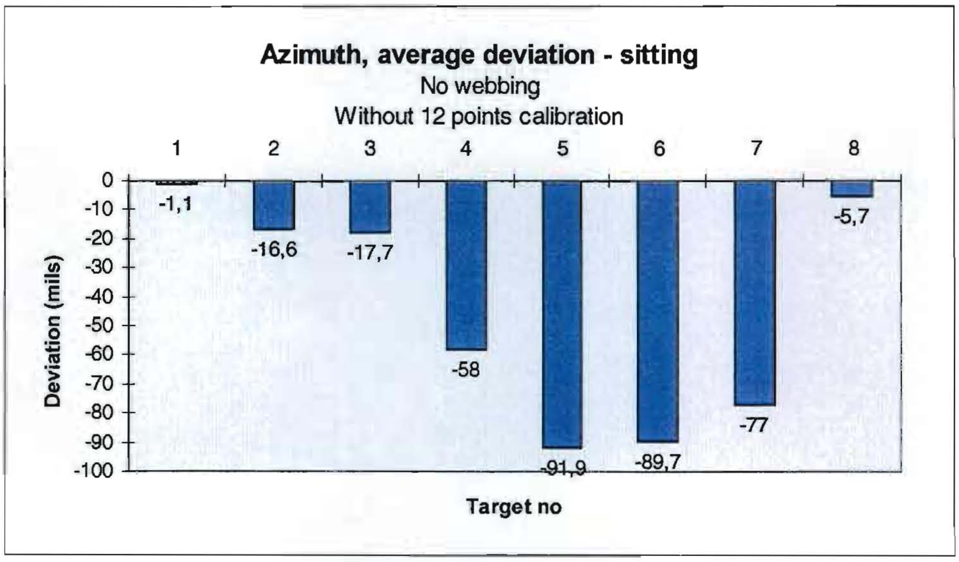

Figure 4.5 Azimuth, sitting, no webbing, without 12-point calibration. Each bar represents the average of 5 measurements.

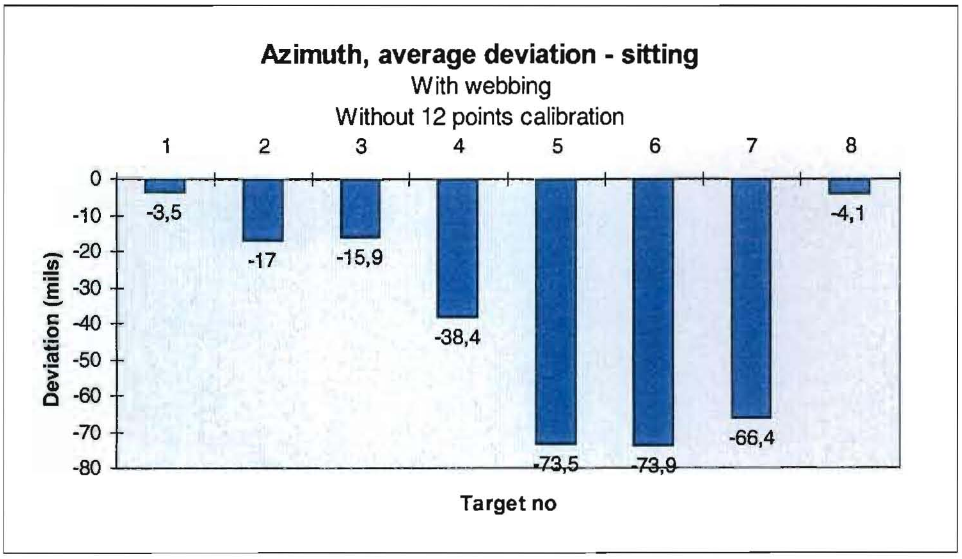

Figure 4.6 Azimuth, sitting, with webbing, without 12-point calibration. Each bar represents the average of 5 measurements.

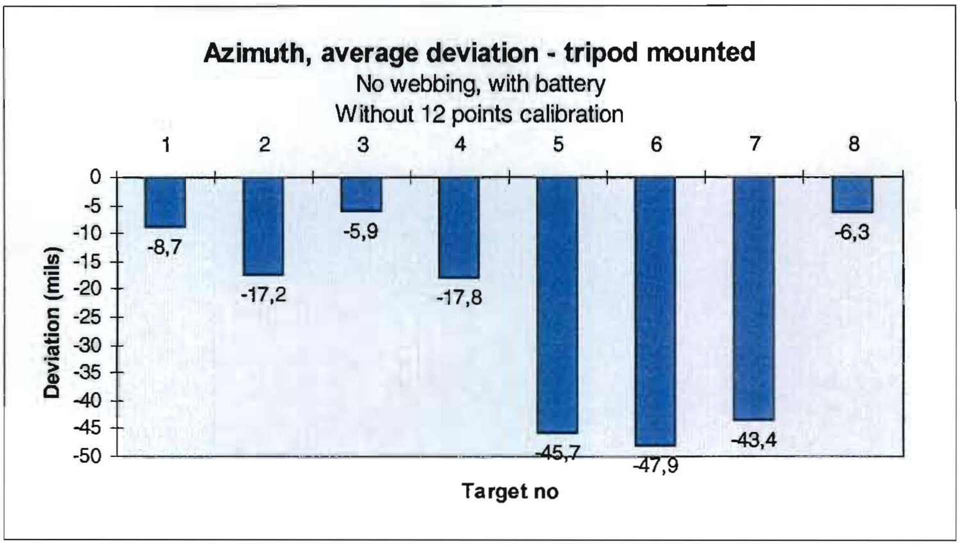

Figure 4.7 Azimuth, tripod mounted, with webbing, without 12-point calibration. Each bar represents the average of 5 measurements.

The large average errors we can see in the figures are due to the poor calibration of the magnetic compass, and the errors illustrate the importance of calibrating the compass when the magnetic environment near the compass is changed (i.e. when magnetic fields with a fixed orientation relative to the compass change).

4.2.3.2 Average Azimuth Error With 12-Point Calibration

After correcting the software bug which had made us unable to carry out the 12-point calibration procedure, we repeated some of the measurements the next day.

Figures 4.8 and 4.9 show the average azimuth error with the operator respectively sitting and standing. The maximum average error is 8.1 mils in both cases. Aiming point 9, which lay between aiming points 6 and 7, is a mast which was not visible during the measurements on the previous day.

With azimuth errors of the magnitude seen here the uncertainty in the local declination will in practice be the dominant source of azimuth error. Measurements carried out by FFI earlier indicate that the magnetic declination can be expected to have a standard deviation due to local variations of 1 - 2.5° (18 - 44 mils), depending on the locality.

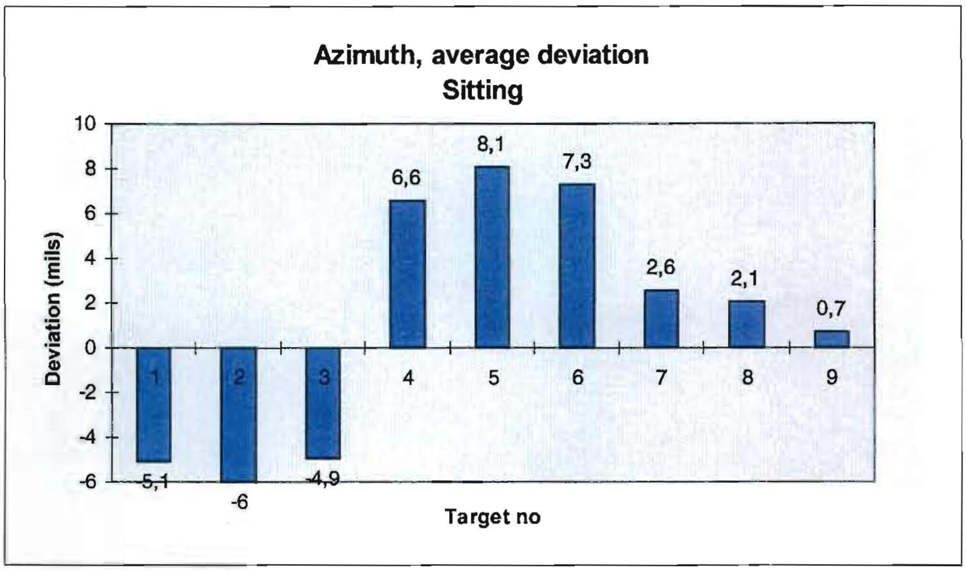

Figure 4.8 Azimuth, sitting, no webbing, with 12-point calibration. Each bar represents the average of 5 measurements.

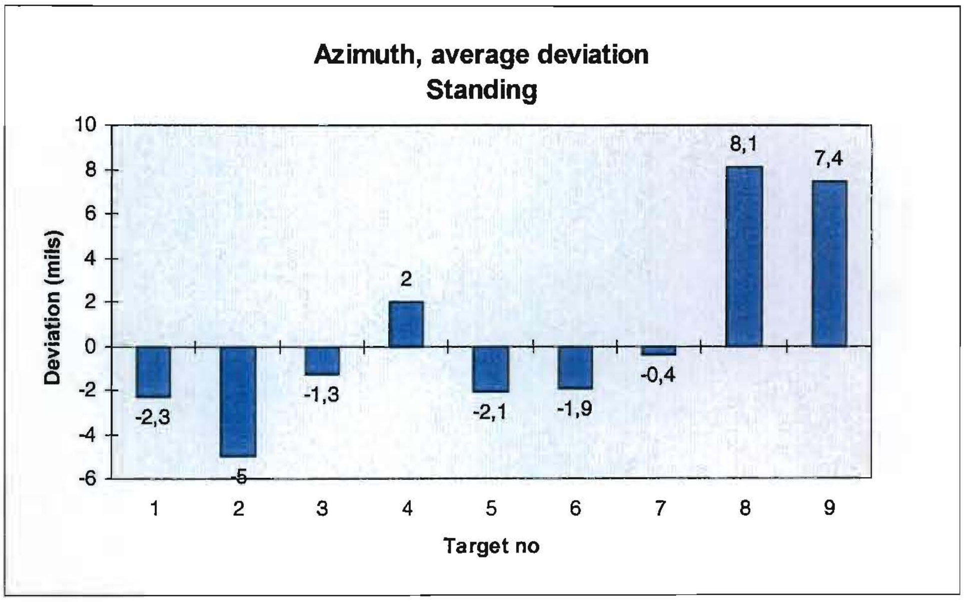

Figure 4.9 Azimuth, standing, no webbing, with 12-point calibration. Each bar represents the average of 5 measurements.

4.2.4 Dispersion of Azimuth Measurements: Dependence on Method of Operation

With the instrument hand-held the aiming skills of the operator will obviously affect the accuracy of the azimuth measurement. Hence we have plotted some results below to show how the dispersion of the measurements about their mean value varies with the different methods of operation and different operators.

There were two different operators of the instrument during the tests at Älvdalen (called "Operator 1" and "Operator 2" below).

4.2.4.1 Dispersion of Azimuth Measurements, Hand-Held - Operator Standing

This way of using the instrument is possibly a bit unrealistic, since in practice the operator will probably try to support the instrument so as to hold it more stable. However, it will represent an upper limit on the dispersion of the measurements due to the operator in hand-held operation.

Figures 4.10 and 4.11 show the dispersion of the azimuth measurements for Operator 1, in the form of a histogram and a plot of the deviation of the individual measurements respectively, while figures 4.12 and 4.13 show the same results for Operator 2. The dispersion of the measurements is significantly greater for Operator 1 than for Operator 2, with standard deviations of 16.9 and 6.3 mils respectively. The difference may to some extent be explained by the fact that Operator 2 had more practice than Operator 1 in the use of the instrument. The laser firing button proved to be a bit stiff, and it probably took some time to get used to using it.

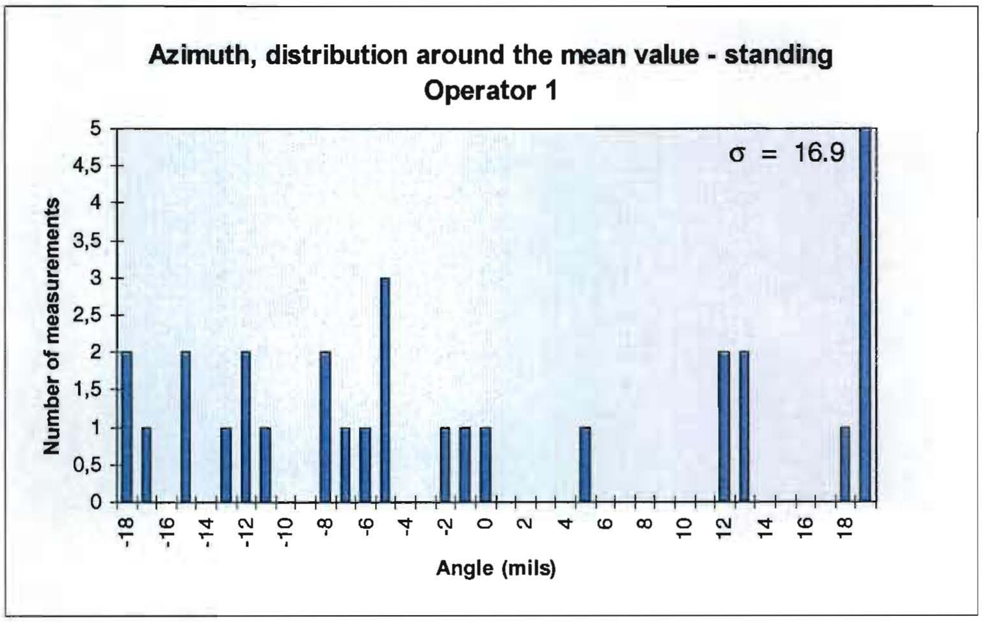

Figure 4.10 Dispersion of the azimuth measurements
Standing - handheld, operator 1.

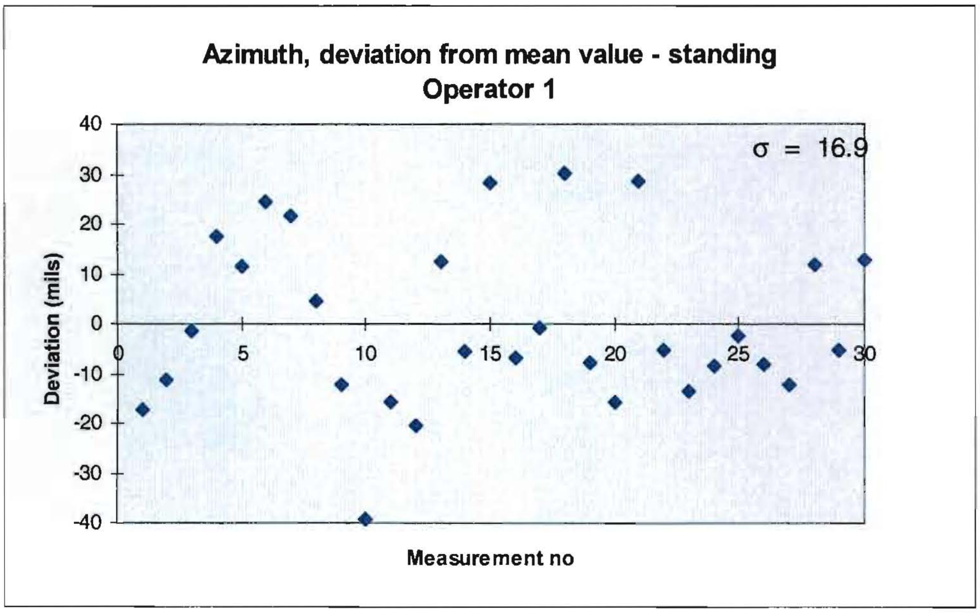

Figure 4.11 Azimuth deviation from mean value. (Same data as in figure 4.10.)

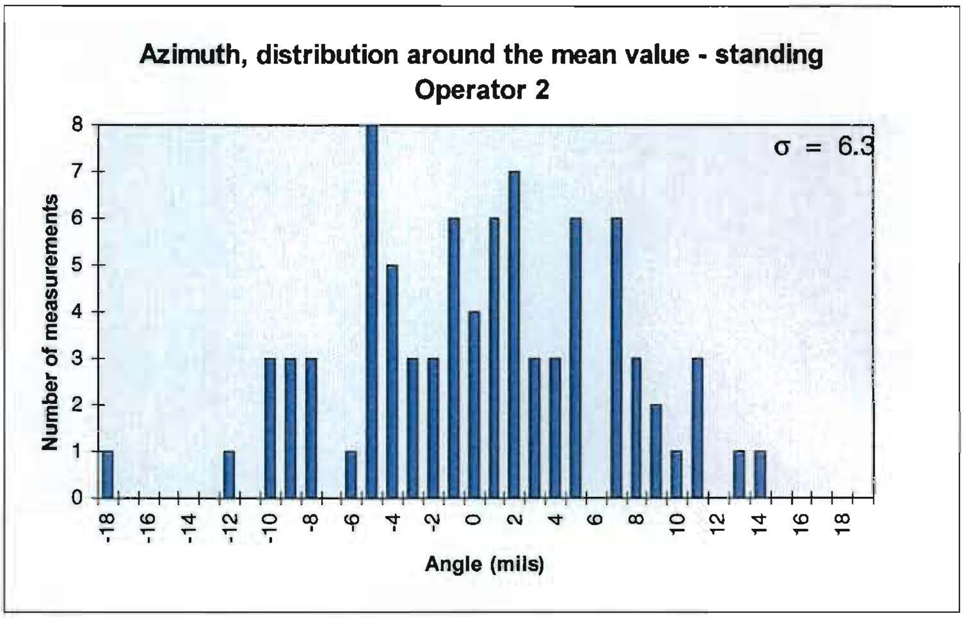

Figure 4.12 Dispersion of the azimuth measurements.
Standing - hand-held, operator 2.

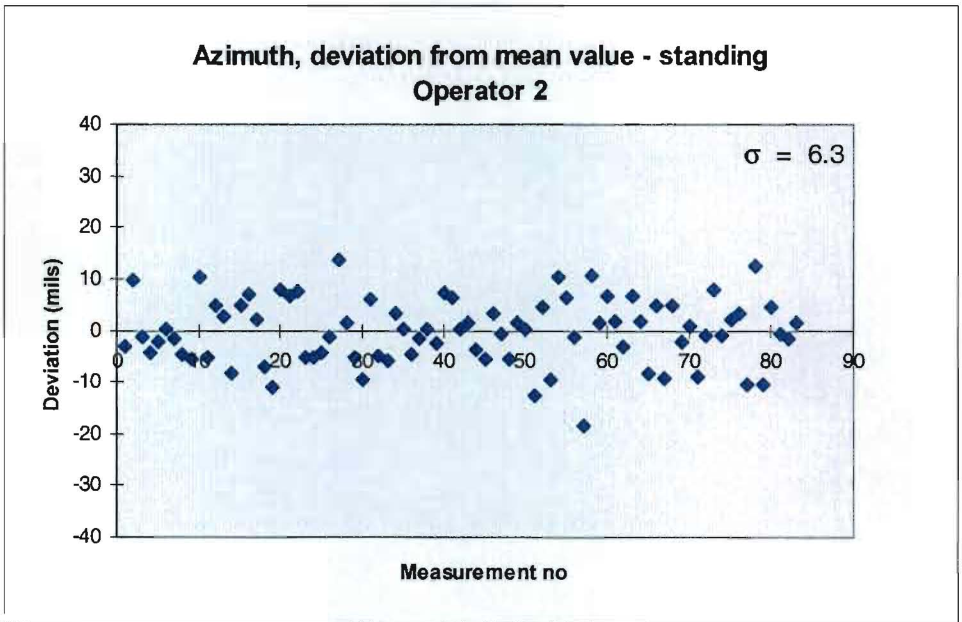

Figure 4.13 Azimuth deviation from mean value. (Same data as in figure 4.12.)

4.2.4.2 Dispersion of Azimuth Measurements, Hand-Held - Operator Sitting

As expected, the dispersion of the measurements with the operator sitting is smaller than with the operator standing. Figures 4.14 and 4.15 show the dispersion of the azimuth measurements for Operator 1, in the form of a histogram and a plot of the deviation of the individual measurements respectively.

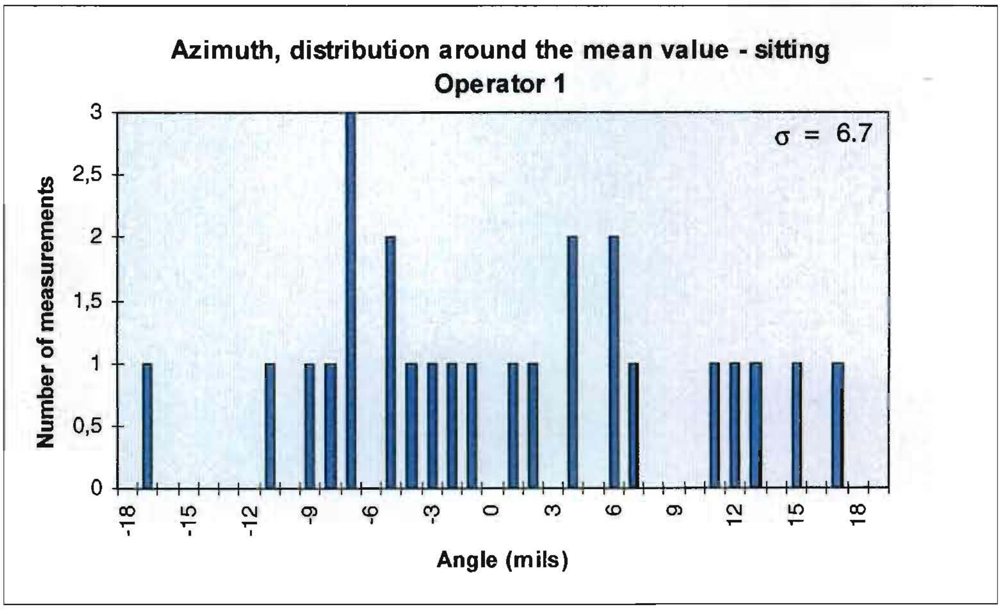

Figure 4.14 Dispersion of the azimuth measurements.
Sitting - hand-held, operator 1.

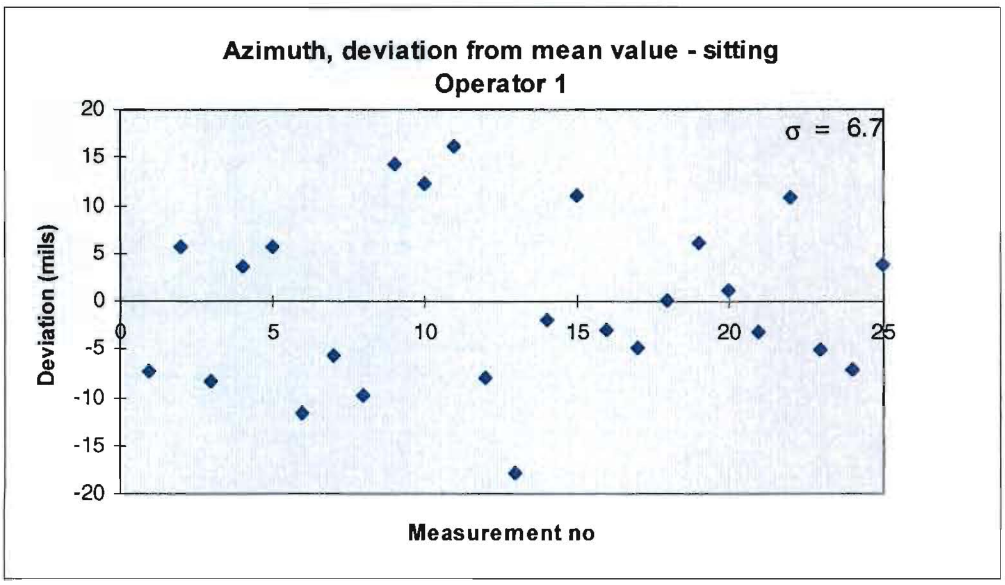

Figure 4.15 Azimuth deviation from mean value. (Same data as in figure 4.14.)

Similar plots for Operator 2 are shown in figures 4.16 and 4.17. Again we can see that the dispersion of the measurements for Operator 2 is less than for Operator 1. The standard deviation is 6.7 and 3.7 mils for Operators 1 and 2 respectively.

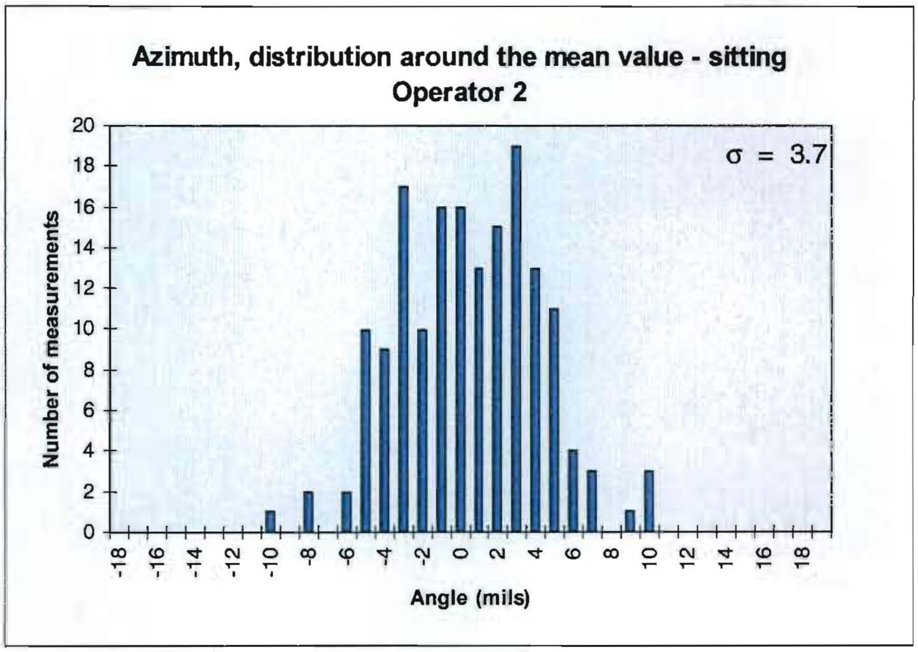

Figure 4.16 Dispersion of the azimuth measurements
Sitting - hand-held, operator 2.

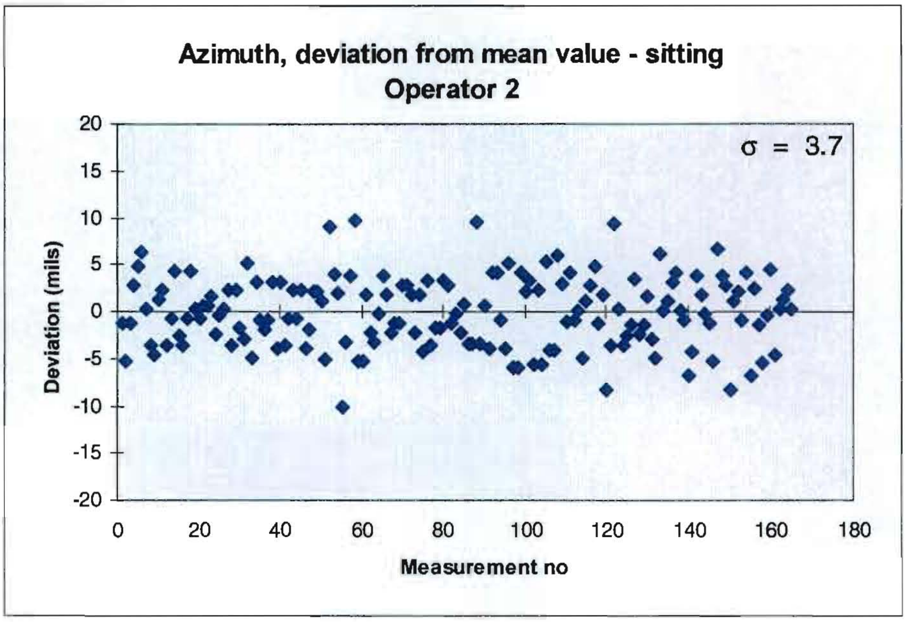

Figure 4.17 Azimuth deviation from mean value. (Same data as in figure 4.16.)

4.2.4.3 Dispersion of Azimuth Measurements, Tripod-Mounted

With the instrument tripod-mounted a major source of the dispersion of the measurements is internal noise in the measurement of the magnetic field by the compass. Figures 4.18 and 4.19 show the dispersion of the azimuth measurements for Operator 1, in the form of a histogram and a plot of the deviation of the individual measurements respectively, while figures 4.20 and 4.21 show the same results for Operator 2. The standard deviation is 2.6 and 1.8 mils for Operators 1 and 2 respectively.

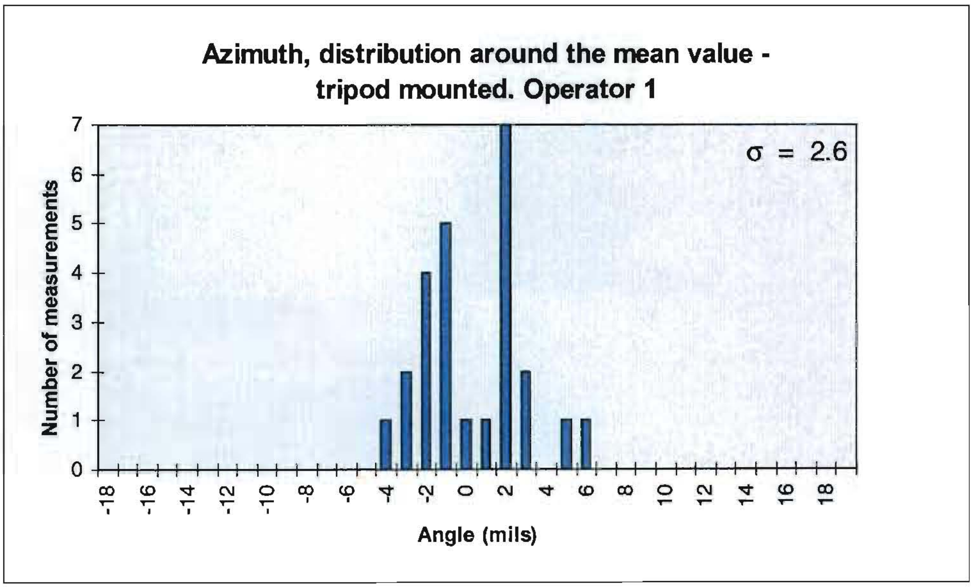

Figure 4.18 Dispersion of the azimuth measurements.
Tripod mounted, operator 1.

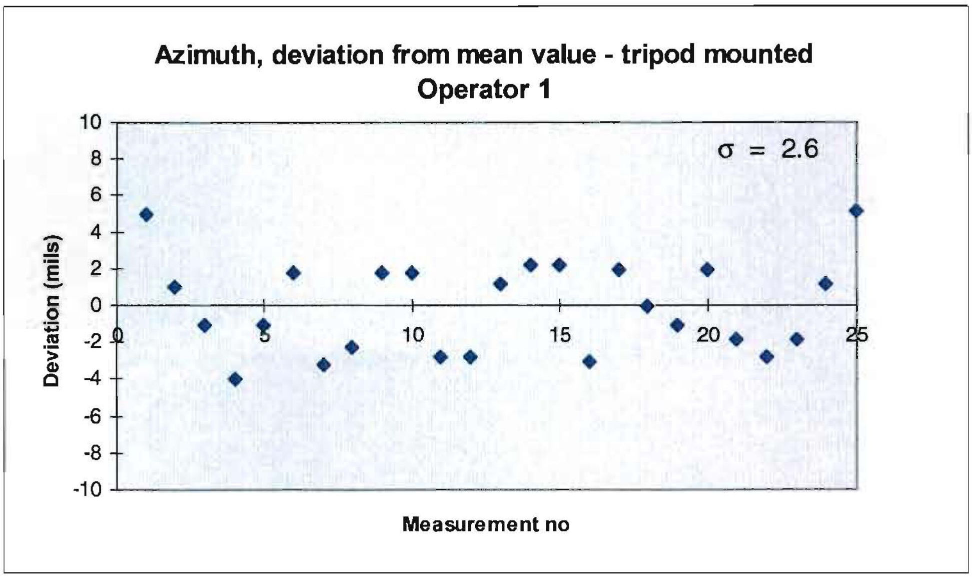

Figure 4.19 Azimuth deviation from mean value. (Same data as in figure 4.18)

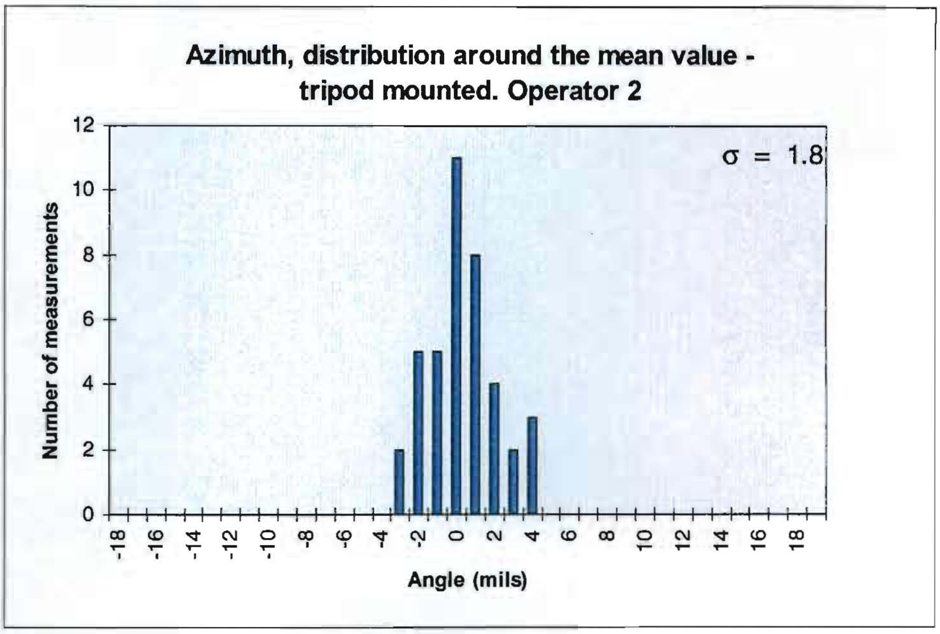

Figure 4.20 Dispersion of the azimuth measurement. Tripod mounted , operator 2.

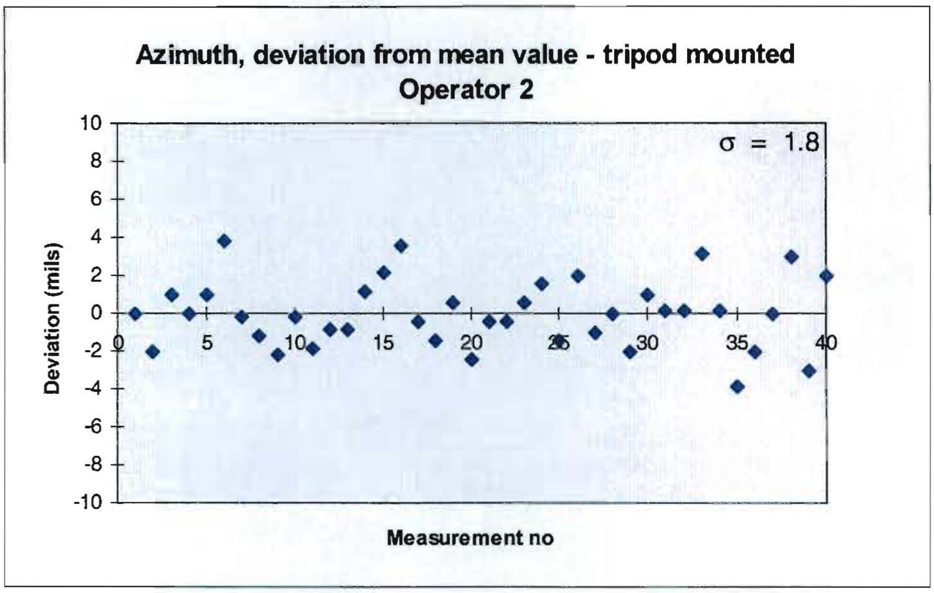

Figure 4.21 Azimuth deviation from mean value. (Same data as in figure 4.20.)

4.2.4.4 Dispersion of Azimuth Measurements - Summary

Table 4.1 is a summary of the standard deviations for the different methods of operation and operators. The values for "Operator 3" are taken from tests carried out in 1996 with the "Test Instrument" Forward Observer Instrument. They are included here for comparison. With the exception of Operator 1 standing, the standard deviations in the table are that low that, with normal practical use of the instrument using the magnetic compass for azimuth measurement, the uncertainty in magnetic declination as well as errors due to imperfect calibration will dominate the azimuth measurement uncertainty.

Operator	Standing	Sitting	Tripod
1	16.9	6.7	2.6
2	6.3	3.7	1.8
3 (test version - 96)	7.1	5.1	1.1

Table 4.1 The table shows the standard deviations (in mils) of the azimuth measurements for different methods of operation and operators. The last row (operator 3) is from the trials with the test version in 1996.

As mentioned above, we have measured the local variation in magnetic declination in certain areas, and shown that the declination in these areas has local variations with a standard deviation of 1 - 2.5° (18 - 44 mils). With these local variations in declination, bearing in mind that the total error will be the individual errors root sum squared (independent stochastic variables), the improvement in azimuth accuracy (when measuring azimuth with the magnetic compass) due to, e.g., using the instrument tripod-mounted rather than hand-held will be small.

4.3 North-Finder Summary Performance

The north-finder functional model was under development until shortly before the tests in Älvdalen Skjutfelt (Älvdalen Firing Range). The north-finder thus was moved directly from the development laboratory to real field environment and functioned fully as expected throughout the test period.

The red curve in figure 4.22 shows predicted performance as a function of north-finding time. The red circles are the result from a large number of laboratory tests. The blue stars indicate results from the tests at Älvdalen (included in these results are not only the actual north-finding errors but also any other measurement error in the complete instrument, for example any error in the goniometer angular measuring device). One can conclude that the standard deviation of the measured results is in good agreement with predicted performance.

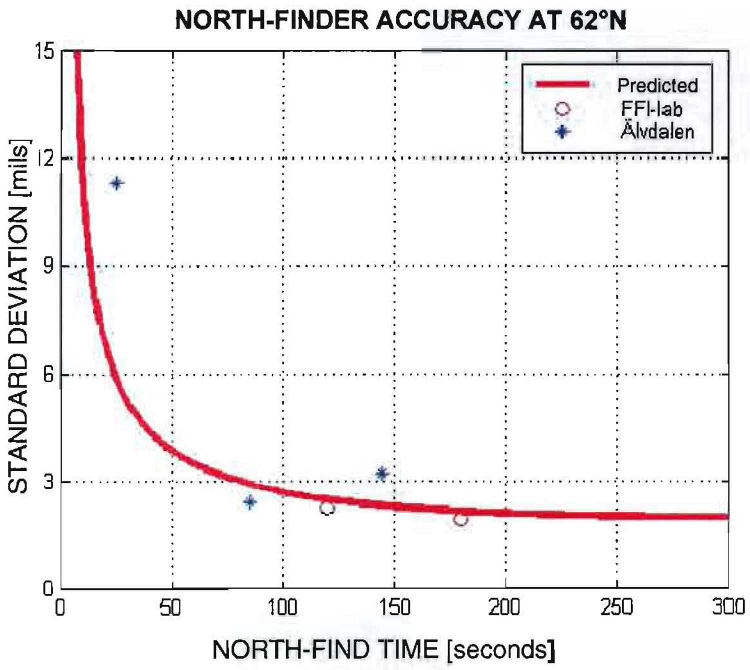

Figure 4.22 Predicted results and results from actual tests

4.3.1 Azimuth References

Line of sight angles to selected aiming points were measured in advance, except that one point, denoted Aiming Point 9 (AP9), could not be seen at that time because of sight limitations due to fog. The direction to AP9, located at a distance of about 2 km, was determined during the tests. All angles to the aiming points were referred to Swedish Grid, RT90 2.5 gon V. However, as the north-finder was set up to output grid angles in UTM WGS84, it became necessary to transform the reference angles correspondingly.

The reference angles were as a first step converted from Swedish mils, "streck", where 6300 streck equals 360°, to mils (6400 mils equals 360°). The second step was to convert the result to UTM SWEREF93 with the kind assistance from Lantmäteriverket in Sweden. For the purpose of these tests WGS84 and SWEREF93 are considered to be equivalent.

To summarise:

From streck to mils: Multiply by 6400/6300.

From mils in the RT90-system to grid north in UTM WGS84 (SWEREF93) at the test site in Älvdalen, located at 61° 23' 58.66" N, 13° 47' 38.86" E: Add -12.6 mils.

Reference angles and the raw measurements are found in appendix C.

Additionally, FFI personnel during the test also measured the directions to the aiming points. The north reference in this case was provided by a special purpose inertial reference system that had an expected accuracy less than one mil.

However, it was later found that these two measurement series differed by about 15 mils. The cause for the discrepancy has not been found and these reference angles are likely to be biased (and possibly both sets are). The aiming reference directions provided to us are used in the following if not otherwise stated. These reference directions results in an average difference between measured and "true" directions of about 5 mils.

On the basis of the reference measured by FFI the direction to AP9 was established and added to the original list of azimuth references.

4.3.2 North-finder Accuracy

North-finder accuracy was determined by sightings towards the different Aiming Points by the Main Module. The results then will have error contributions from the total measurement chain. (Sum of north-find error and, if any, transformation errors in the goniometer, errors in the goniometer angular measurement device, mechanical alignment of the measurement chain and aiming errors.)

During the Älvdalen tests a total of 21 independent north-findings were performed. It is reckoned that this is a relatively low number of tests to conclude on the statistical performance. Here, independent north-finding means that only one aiming direction is used to determine the north-finder error as the corresponding errors with respect to the other Aiming Points are highly correlated.

Figure 4.23 are histograms that show the results from all independent north-findings with a nominal duration from one to three minutes. Note that the effective gyro measuring time was about 35 seconds less than these times due to present limitations in the functional model. The actual time used for the north-finding algorithms then were about 30, 90 and 150 seconds compared to the total of 1, 2 and 3 minutes. The results in figure 4.22 are corrected to reflect the actual time used to find north.

The main conclusion was that the functional model performed as expected. Also, the obtained accuracy was satisfactory and quite close to laboratory results. However, the results exhibit a mean error of about 5.5 mils. This may be contributions from zero alignment errors in the total Forward Observer Instrument or error in the reference aiming directions. In both cases these error sources can be rectified and are at present not considered any further.

During post processing of the measurements significant direction dependent aiming errors were found when the instrument was tilted. The cause was found to be an elevation angle measurement error. The resulting aiming errors could be calculated and used to correct the measurements. The errors then were reduced from more than 6 mils to about 1 mil. More details are found in 4.3.3.

As expected the north-finder errors increase with decreased north-find time. This effect can quite clearly be seen on the plot of the one-minute tests, but not on the two and three minute tests due to the low number of measurements.

In the laboratory a large number of north-findings, about 2000, provide a fairly good statistical base. The points marked "FFI-lab" (small circles) in figure 4.22 are the summary results from these tests (transformed to 62°N, latitude of Älvdalen Firing Range).

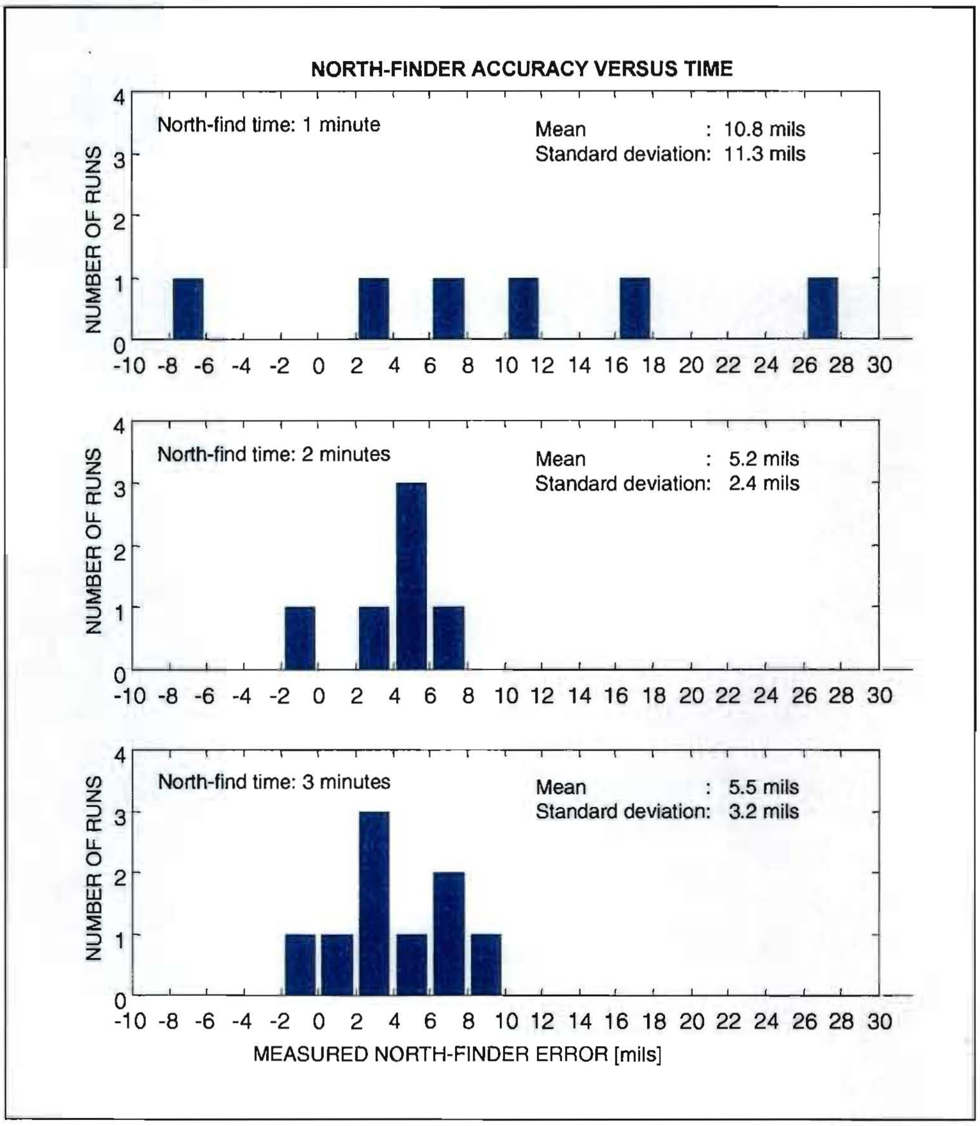

Figure 4.23 Histogram of all independent north-finder results

4.3.3 Influence From Instrument Tilt On North-finder Accuracy

During these tests accurate levelling of the instrument (including the north-finder) was not emphasised. During the first runs the resulting tilt angles happened to be 1.8° and 2.0°, about the north-finders mechanical zero- and across axes respectively. The 11 first tests were run with these tilt angles. Then the tilt angles were purposely set to larger values, to about -7.7° and 3.3°. The total change in tilt thus was close to 10°. The results from all north-findings measured towards AP6 are shown in figure 4.24.

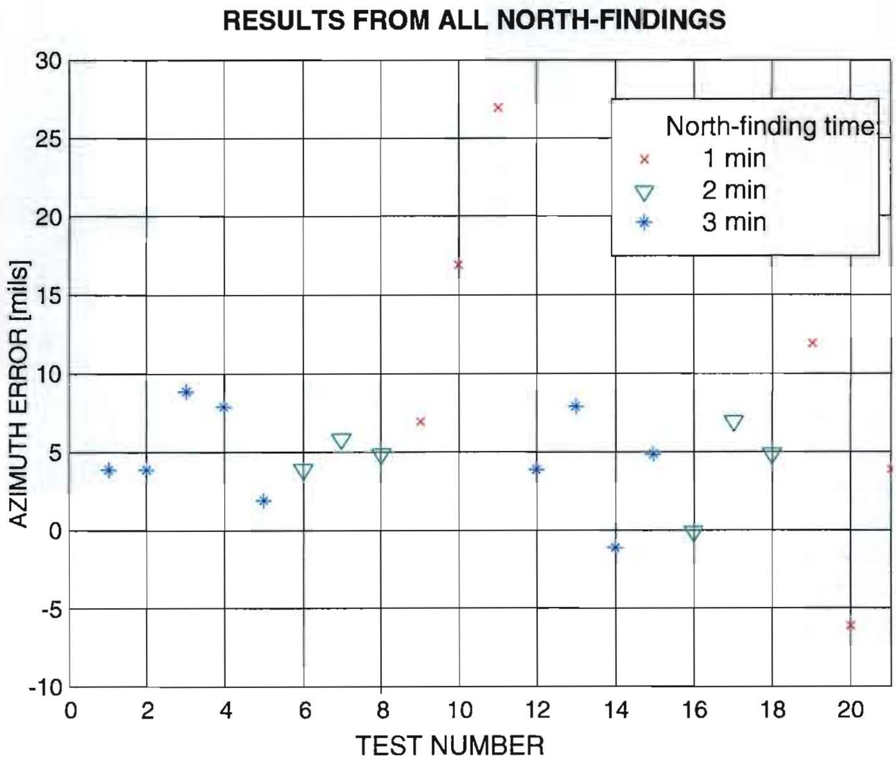

Figure 4.24 All north-findings referred to AP6. Tilt angles increased after run no 11

Three measurement series were performed with measurements towards AP1 to AP8. Each series was based on one north-find. Series 1 and 2 were run with the relatively small tilt angles while series 12 was done with the larger tilt angles. The corresponding results are shown in the top plot in figure 4.25.

It was evident that the aiming errors were direction dependent, and this was more clearly seen after increasing the tilt angles. This effect could not be caused from north-finder inaccuracy since that would influence all measurements equally. An inaccurate accelerometer scale factor would result in inaccurate tilt angles and, accordingly, the goniometer transformations would be based on incorrect tilt angles. System simulations show that relatively large tilt errors were required to get errors of the size indicated in the figure and, in that case, the north error would be much larger than was actually seen.

The actual cause for the error was found to be a difference between two simultaneous target elevation angle measurements. The first measurement was done by the DMC inside the goniometer and used in the goniometer-transformations while the second measurement, used for calculation of target elevation angle, was done within the Main Module by another DMC. Ideally, these two measurements should have been equal, however, they were found to differ by 1.5°. With the instrument in a tilted position elevation angle errors will contribute to direction errors which become larger with larger tilt angles.

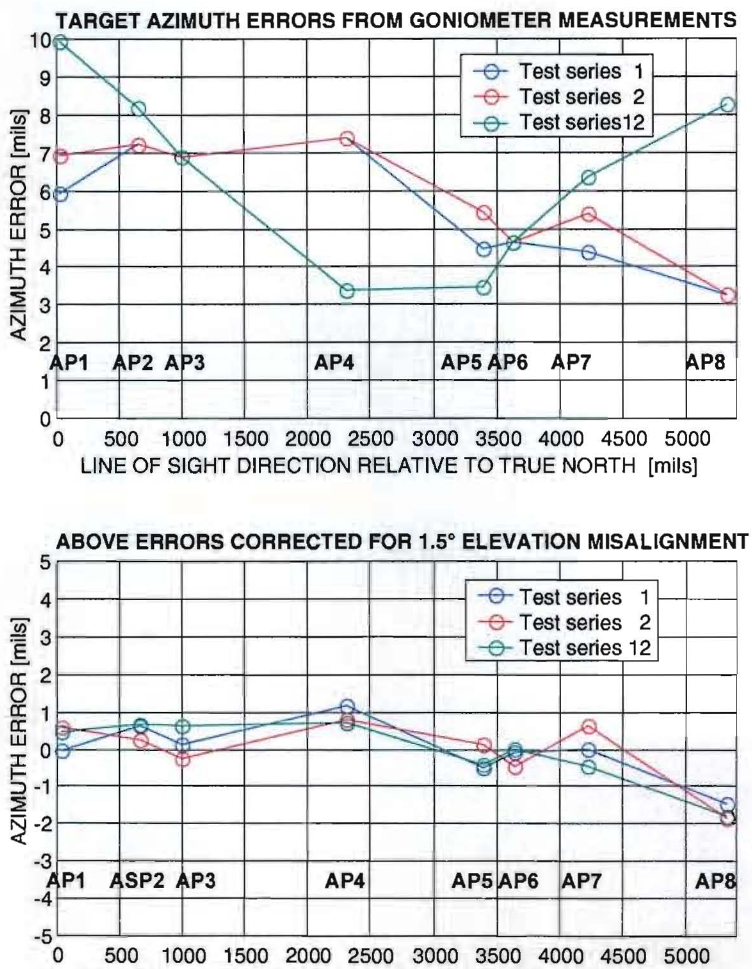

Figure 4.25 Target azimuth errors towards Aiming Points 1 to 8 before and after correcting for 1.5° elevation angle error. Note that in the lower plot the mean difference is set to zero.

The measurements were post processed and corrected by subtracting the corrections due to the use of the incorrect elevation angles and then adding the correct values. The results are shown in the lower plot of figure 4.25 (note that the mean difference was set to zero). The original variation of close to 7 mils became reduced to 2.5 mils and the shapes of the error curves now are very similar for both small and large instrument angles.

Figure 4.26 shows the measured aiming errors for measurement series 12 using two different sets of line of sight reference directions: the red curve was based on the original measurements and the blue curve was based on the FFI measurements. When using the FFI measurements the maximum variations for measurement series 12 was further reduced from 2.5mils to 1.2mils (note that the mean difference was set to zero) which indicate that the FFI measured reference directions are likely to be the most accurate.

These results indicate that the angle transformations within the goniometer, as proposed by FFI and implemented by Leica, are correct.

It may seem like that the family of curves tends to fall off towards the right. Since this effect was small the cause for this was not pursued any further at that time.

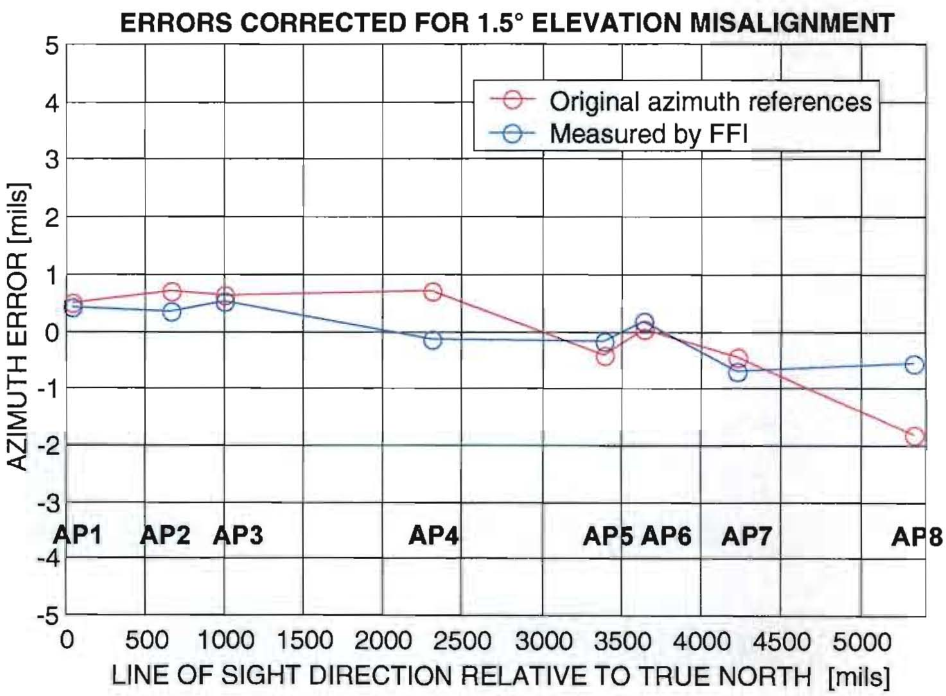

Figure 4.26 Corrected aiming error toward Aiming Points 1 to 8 with reference to both the original and to the FFI measured reference directions

4.4 Elevation Measurement

As mentioned previously, the digital magnetic compass is a three-axis instrument (the magnetic field is measured in three orthogonal directions), and it incorporates two tilt sensors to determine the orientation of the compass. Thus the compass is able to determine the direction of the magnetic field even when it is tilted. The Functional Model of the Forward Observer Instrument always measures elevation using one of the tilt sensors in the digital magnetic compass in the Main Module. When operating tripod-mounted the elevation could have been read out from the goniometer, but since the SG12 goniometer uses the same tilt sensor for measuring elevation (the SG12 incorporates the same magnetic compass as the Main Module) there is no reason for not using the tilt sensor in the compass in the Main Module.

Regrettably, no elevation reference measurements were carried out, thus we can only look at the dependence of the dispersion of the elevation measurements about their mean value on the alternative methods of operation.

4.4.1 Dispersion of Elevation Measurements: Dependence on Method of Operation

As with azimuth measurements the operator's aiming skills will contribute to the accuracy of the elevation measurement. Here we have plotted some results to show how the dispersion of the measurements about their mean value varies with the method of operation for the two operators.

4.4.1.1 Dispersion of Elevation Measurements, Hand-Held - Operator Standing

As mentioned previously, hand-held operation with the operator standing is probably somewhat unrealistic, however this represents an upper limit on the dispersion of the measurements with hand-held operation (factors such as wind, fatigue, cold, the threat scenario, etc. will of course also affect the measurements). Figures 4.27 and 4.28 show the dispersion of the elevation measurements for Operator 1 in the form of a histogram and a plot of the deviation of the individual measurements respectively. Similar plots for Operator 2 are shown in figures 4.29 and 4.30. The standard deviation is 4.8 and 2.5 mils for Operators 1 and 2 respectively.

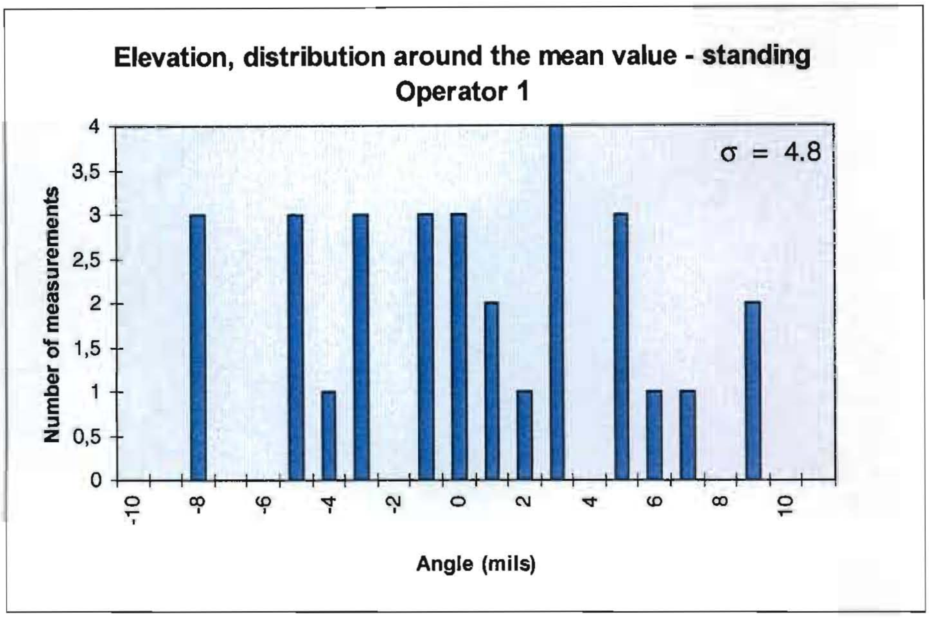

Figure 4.27 Dispersion of the elevation measurement.
Standing - hand-held, operator 1

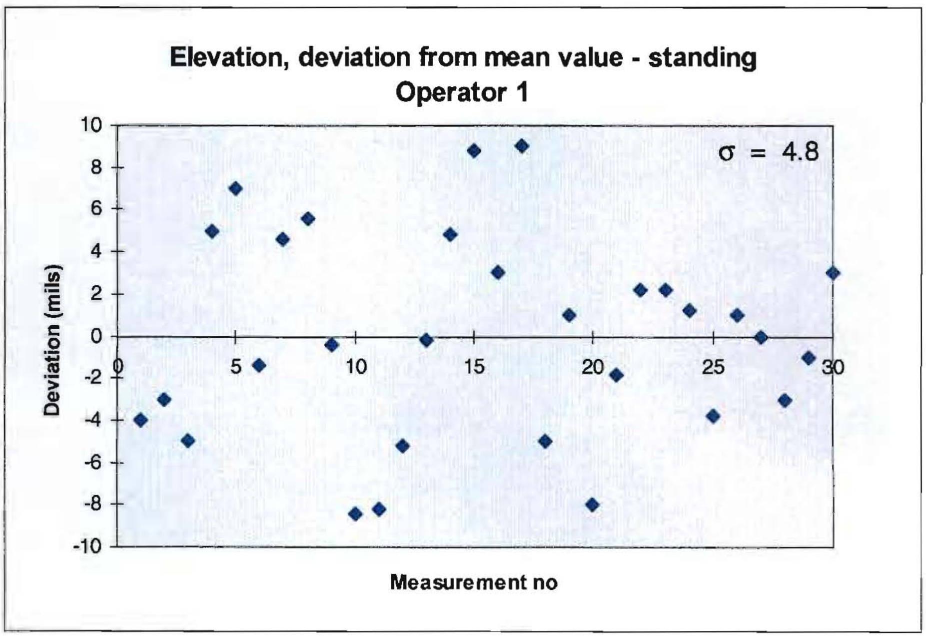

Figure 4.28 Elevation deviation from mean value. (Same data as in figure 4.27.)

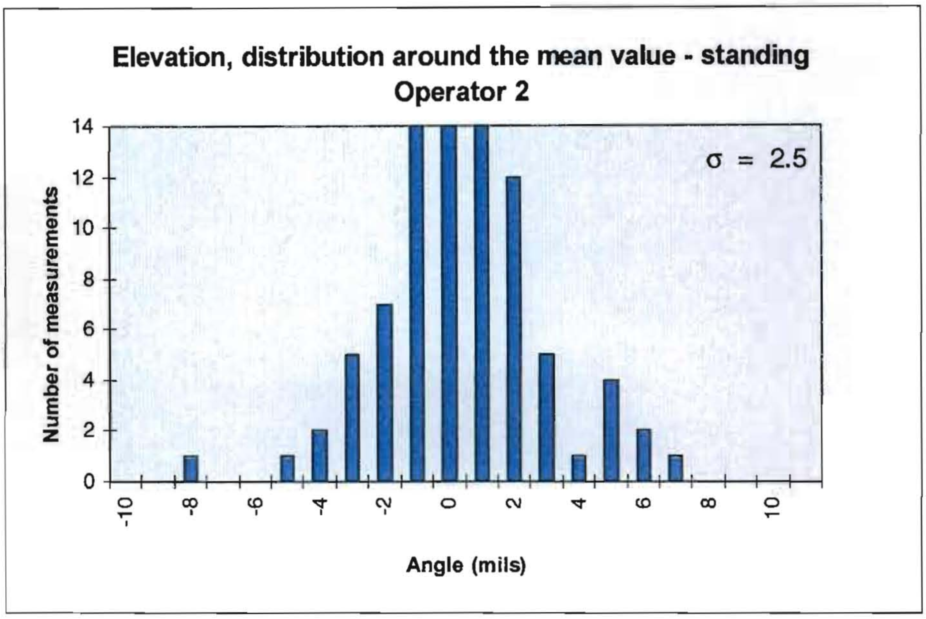

Figure 4.29 Dispersion of the elevation measurement. Standing - hand-held, operator 2

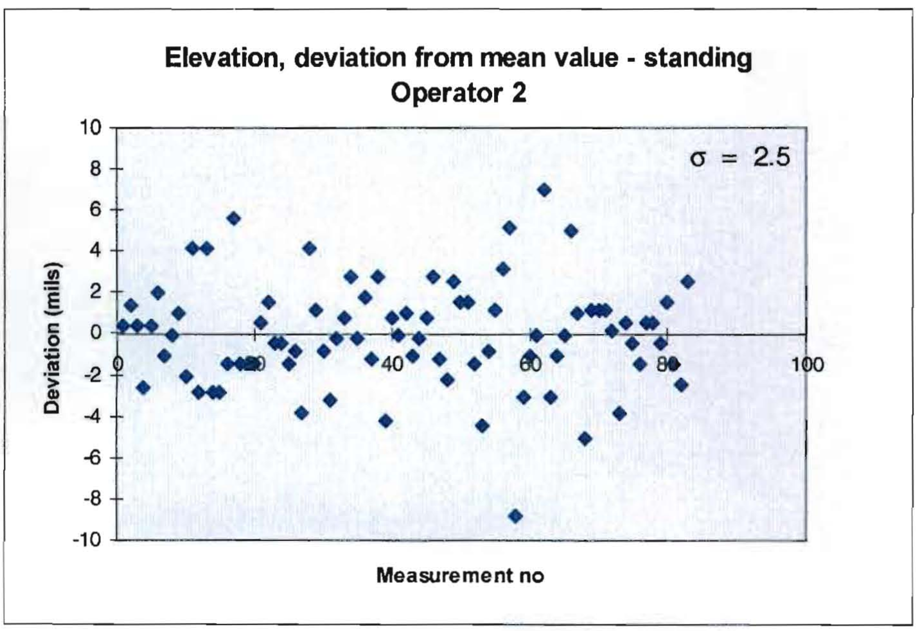

Figure 4.30 Elevation deviation from mean value. (Same data as in figure 4.29.)

4.4.1.2 Dispersion of Elevation Measurements, Hand-Held - Operator Sitting

As expected, the dispersion of the measurements with the operator sitting is somewhat smaller than with the operator standing. The standard deviation is 3.4 and 1.6 mils for Operators 1 and 2 respectively. Figures 4.31 and 4.32 show the results for Operator 1, with similar plots for Operator 2 shown in figures 4.33 and 4.34.

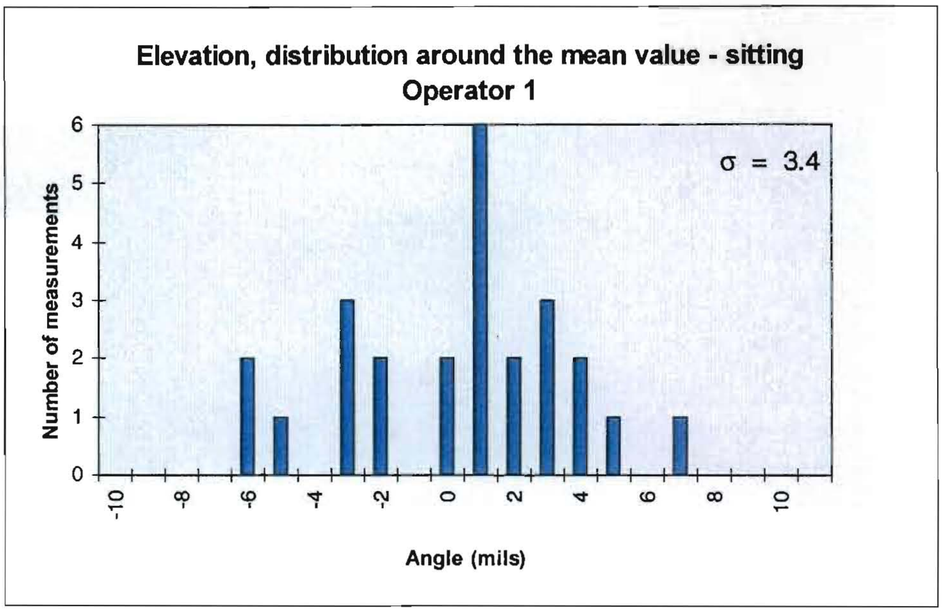

Figure 4.31 Dispersion of the elevation measurement.
Sitting - hand-held, operator 1

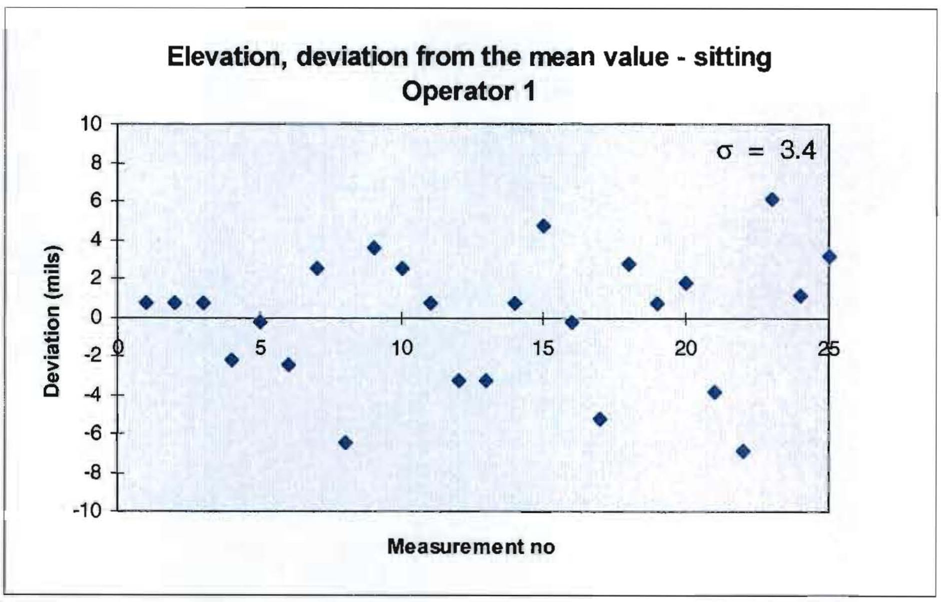

Figure 4.32 Elevation deviation from mean value. (Same data as in figure 4.31.)

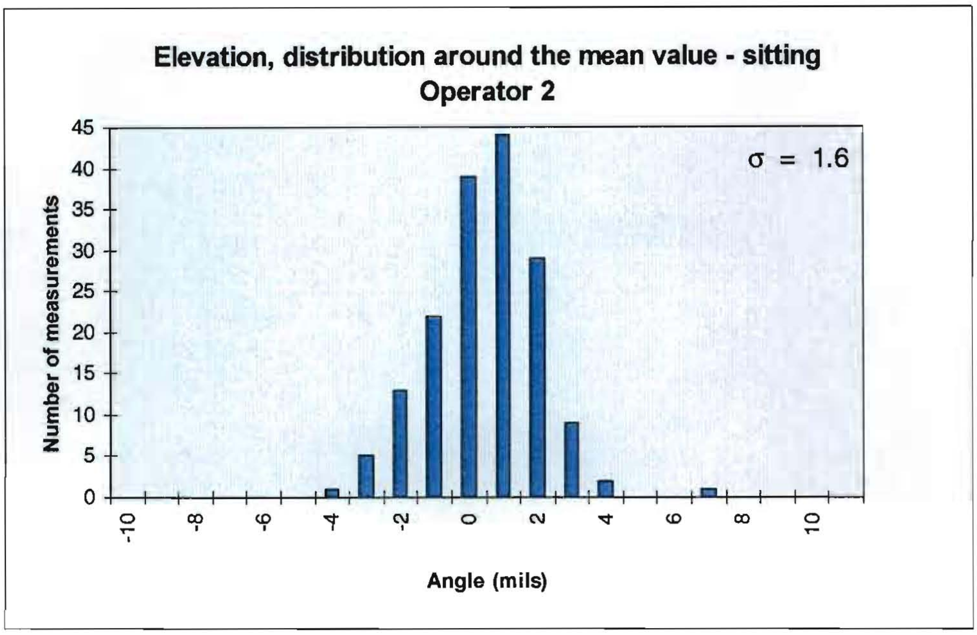

Figure 4.33 Dispersion of the elevation measurement.
Sitting - hand-held, operator 2

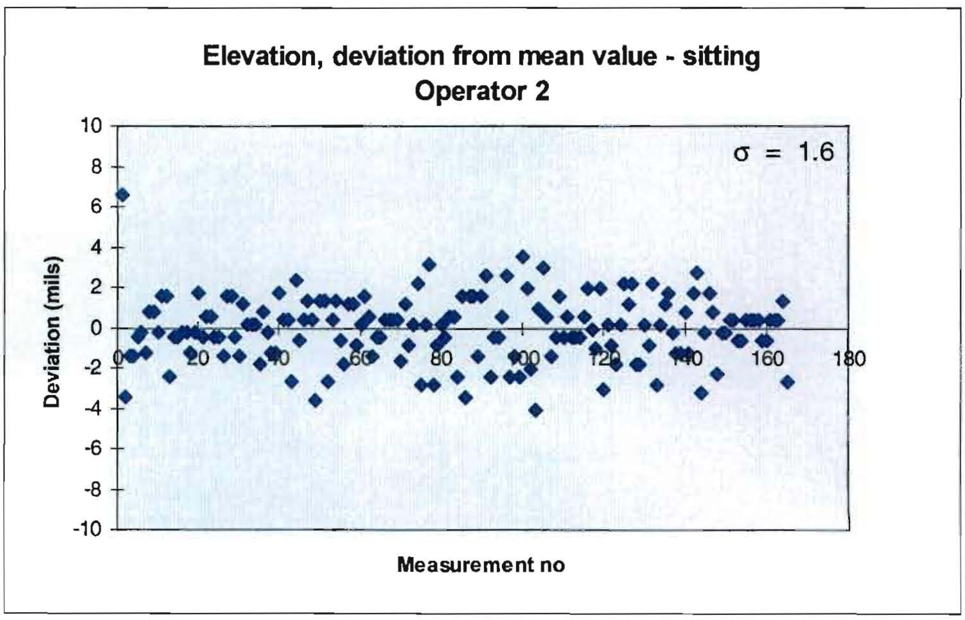

Figure 4.34 Elevation deviation from mean value. (Same data as in figure 4.33.)

4.4.1.3 Dispersion of Elevation Measurements, Tripod-Mounted

Figures 4.35 and 4.36 show the results for Operator 1, while the results for Operator 2 are shown in figures 4.37 and 4.38. The standard deviations for the two operators are quite similar, 0.7 mils for Operator 1 and 0.6 mils for Operator 2.

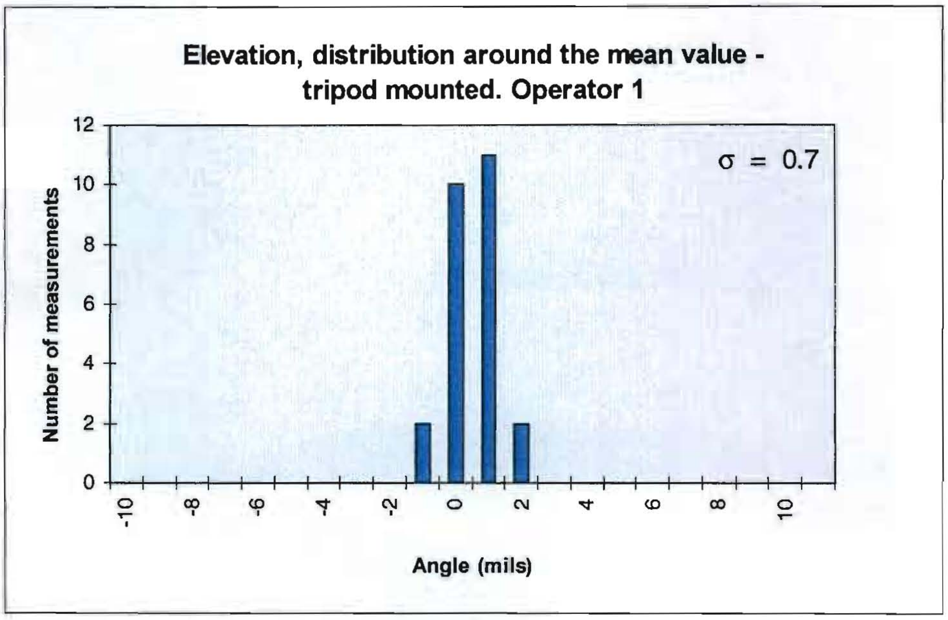

*Figure 4.35 Dispersion of the elevation measurement.
Tripod mounted, operator 1*

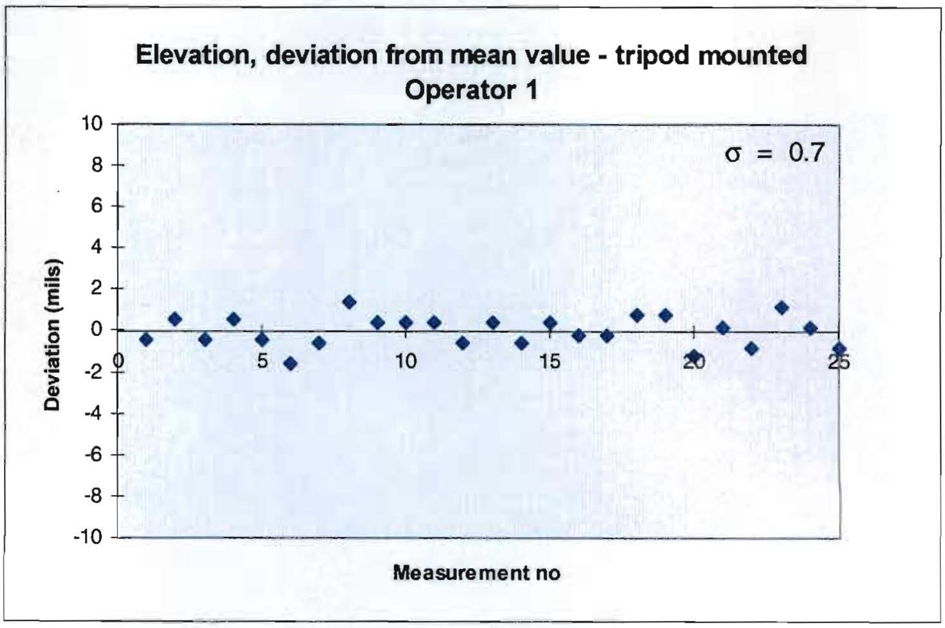

Figure 4.36 Elevation deviation from mean value. (Same data as in figure 4.35.)

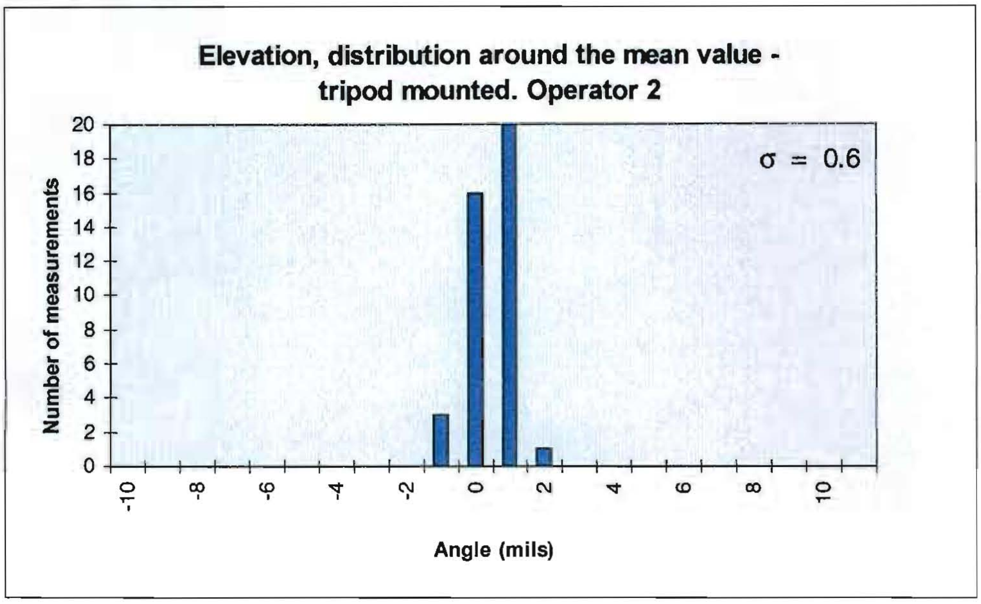

Figure 4.37 Dispersion of the elevation measurement.
Tripod mounted, operator 1

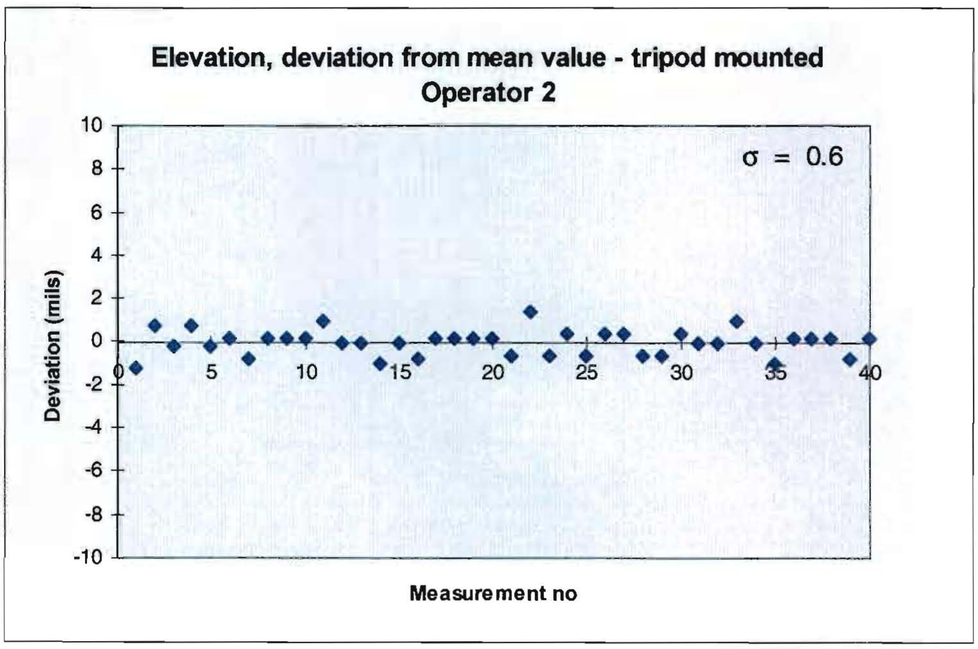

Figure 4.38 Elevation deviation from mean value. (Same data as in figure 4.37.)

The elevation measurement accuracy with the Main Module tripod-mounted is to a great extent a measure of the elevation sensor's own accuracy. According to the manufacturer's specification the elevation sensor (the tilt sensor in the compass) should have a standard deviation of less than 3 mils within the whole measurement range of ±35°. Since we did not have an elevation reference measurement we have not calculated the average elevation error, but purely the dispersion of the measurements about their mean value.

4.4.1.4 Dispersion of Elevation Measurements - Summary

Table 4.2 is a summary of the standard deviations for the different methods of operation and operators. Here too the values for "Operator 3", taken from tests with the "Test Instrument" Forward Observer Instrument in 1996, are included for comparison. Although the azimuth measurements that are based on measurement of the magnetic field have somewhat more noise than the elevation measurements (one can see this by comparing the tripod-mounted results in table 4.1 with those in table 4.2), one can see that the dispersion of the measurements with the Main Module hand-held is significantly smaller in elevation than in azimuth, which indicates that the instrument is held more stable vertically than horizontally. However, it is possible that fluctuations in the tilt of the instrument (and hence its digital magnetic compass) can amplify azimuth measurement fluctuations, since tilt is used in calculating magnetic azimuth.

Operator	Standing	Sitting	Tripod
1	4.8	3.4	0.7
2	2.5	1.6	0.6
3 (test version - 96)	2.7	2.3	0.3

Table 4.2 *The table shows the standard deviations (in mils) of the elevation measurements for different methods of operation and operators. The last row (operator 3) is from the trials with the test version in 1996.*

4.5 Range-Finding

During the trials at Älvdalen no exact range reference measurements were carried out, unlike during the trials of the "Test Instrument" at Haslemoen, Norway, in 1996. At Älvdalen a vehicle fitted with an inertial navigator was used to determine the position of the range-finding targets used. The accuracy of these position determinations was claimed to lie within 10 m. The visibility of some of the targets was partially hindered by vegetation. Hence, where the measured range was significantly shorter than expected, the laser beam probably hit the vegetation. Other possible sources of error include the possibility that the vehicle in some cases may have been placed incorrectly relative to the target, and that the inertial navigator error may have been greater than expected.

Since the range reference measurements had an element of uncertainty, the range-finding measurements at Älvdalen cannot be used to determine the range-finder's absolute accuracy. The range-finder accuracy is, however, to a great extent determined by the accuracy of the clock frequency used in the counter that measures the time between the transmitted and received laser pulses. The counter circuit is the same as that used in other lasers made by Simrad Optronics, and measurements with the laser range-finder have a similar accuracy to those with, e.g., the LP7. To some extent field trials can give an impression of the measurement uncertainty with the alternative methods of operation (hand-held with the operator standing or sitting, or tripod-mounted). However, the uncertainty will vary with the operator, and all the range measurements were carried out by the same operator.

Figures 4.39 to 4.41 are plots of the deviation of the individual measurements for the different methods of operation. There were five targets, and the range to each target was measured five times. In figure 4.39 the measurements to the first target (measurements 1 - 5) were repeated (measurements 26 - 30). As expected, we can see that the dispersion of the measurements depends on how well the instrument is supported. The standard deviations for hand-held operation with the operator standing and sitting are respectively 58.4 and 34.2 metres, while that for tripod-mounted operation is 18.5 metres. For comparison, the equivalent measurements with the "Test Instrument" hand-held with well defined targets (buildings) at Haslemoen in 1996 gave a maximum standard deviation of 3.4 metres.

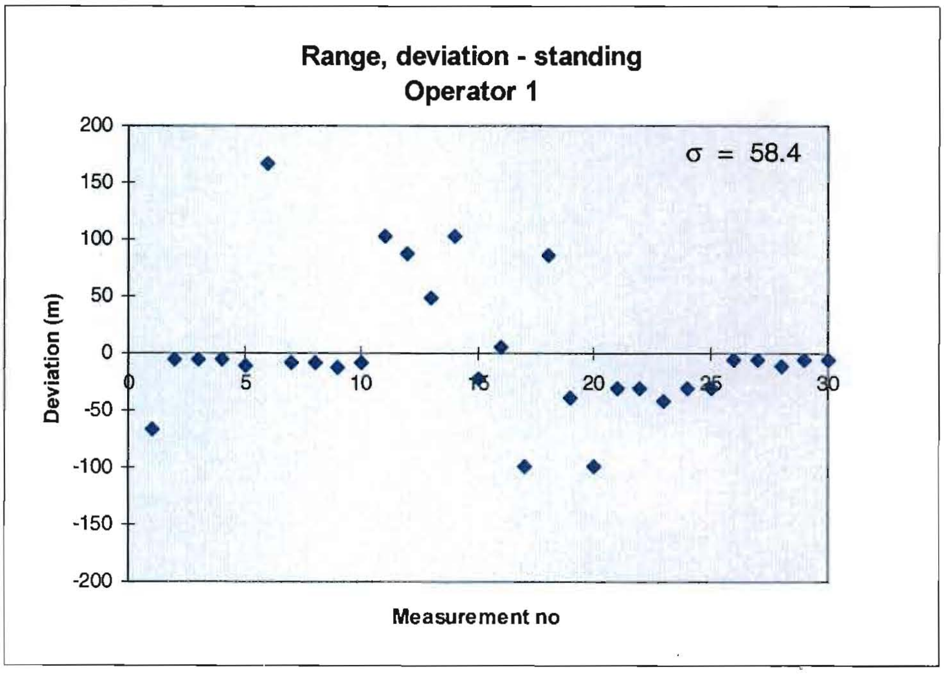

Figure 4.39 Range deviation standing - hand-held

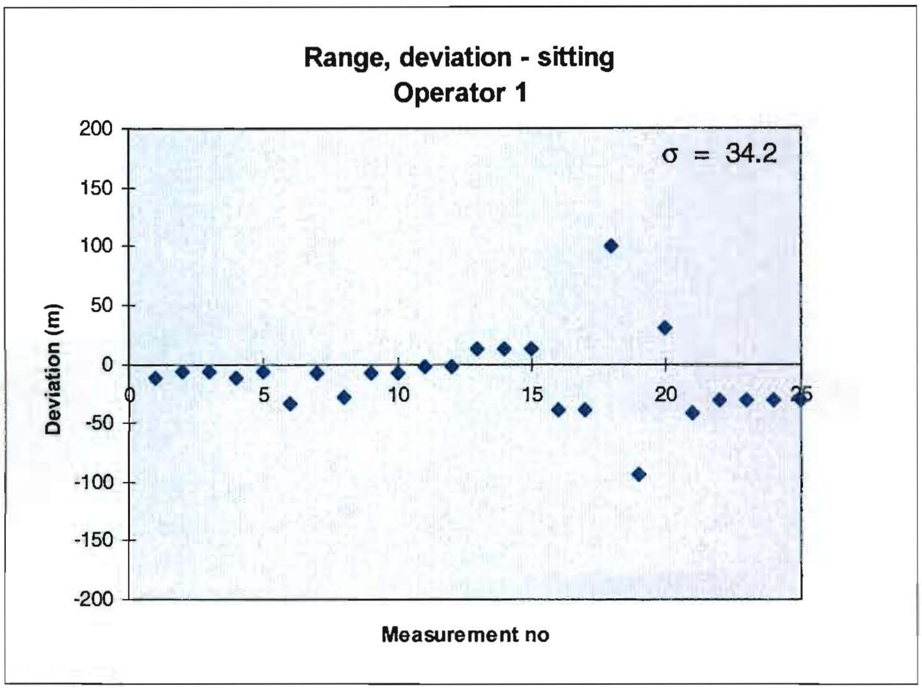

Figure 4.40 Range deviation sitting - hand-held

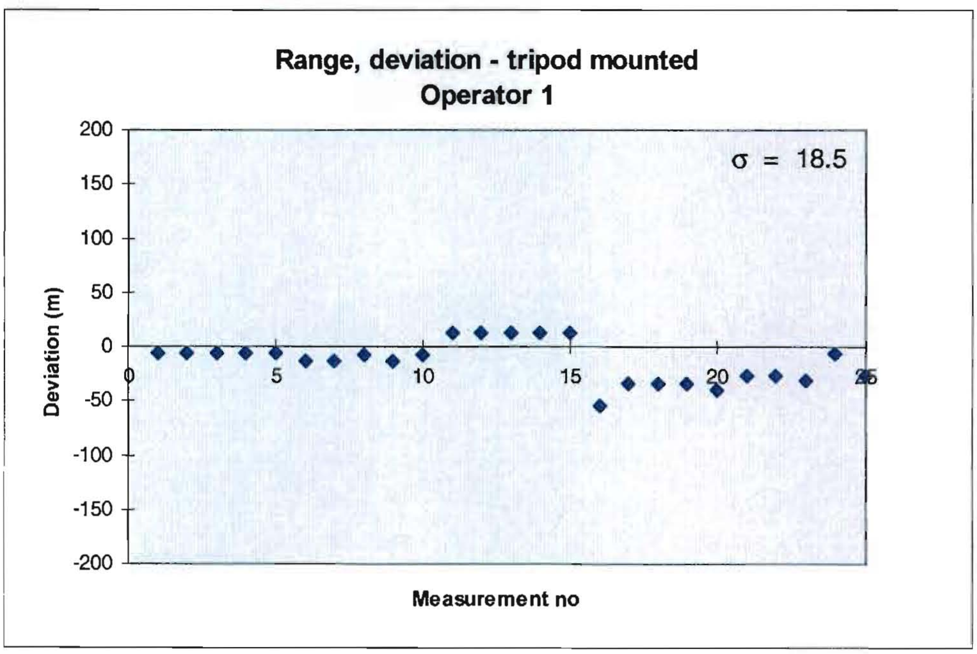

Figure 4.41 Range deviation - tripod mounted

4.6 GPS Measurements

Prior to the trials at Älvdalen, Sweden, we submitted a procedure for the use of the Forward Observer Instrument with a GPS PPS (Precise Positioning Service) receiver fitted, and asked for the procedure to be approved, or alternatively altered. Regrettably, our application was not answered in time, and hence the Main Module was fitted with an SPS (Standard Positioning Service) receiver instead of the PPS receiver. The printed circuit GPS receiver used in the Main Module is available in both PPS and SPS versions, and (with the exception of a couple of integrated circuits) the two versions are physically identical, and have the same digital interface.

The accuracy of the GPS PPS (in "normal" conditions) is well known, and confirmed by tests by FFI, among others. It would, however, have been interesting to measure some parameters concerning the internal GPS receiver in the Main Module, but since we could not use the GPS PPS, we chose not to carry out these tests.

5 INSTRUMENT ERGONOMICS

It would ultimately be reasonable to rely on user reactions to judge the ergonomics of the instrument. However, below we discuss some aspects of the ergonomics that we have paid attention to during the development of the instrument, and some aspects we have become aware of during the trials at Älvdalen.

5.1 A Single User Interface

As we have mentioned previously, the operation of the whole instrument is controlled by the Main Module, using the same operator interface whether it is used hand-held or tripod-mounted with the north-finder and goniometer. This ought to make it easier and quicker for the operators to learn to use the instrument than if they had to learn to use several different interfaces.

Although it is sensible to limit the amount of information the operator is presented with, the VGA display with its 640×480 pixels gives far greater possibilities for presenting information in a user-friendly fashion than, say, a small liquid crystal display would. It is also undesirable to have an external display from the point of view of its visibility in the dark. Using an external display (such as the liquid crystal display on the goniometer) would necessitate back-lighting it for night-time operation, which would increase the risk of being observed with image intensifiers.

5.2 The Main Module Controls

Mode selection and operation of the instrument are controlled by the Main Module's three knobs and buttons. In the Functional Model we chose to have the Enter and laser Fire buttons on the left, and the 4-position control knob on the right. This was because we thought the operator would be using the 4-position control knob (when making menu selections etc.) more often than the Enter and Fire buttons, and that it was therefore more natural to have the 4-position control knob on the right. The operators, however, are used to having the Fire button on the right on other range-finders (e.g. the LP7), and therefore it would be more natural for them to have it on the right. Furthermore, the 4-position control knob is not used as much as we at first thought it would be.

The stiffness of the Enter and Fire buttons (i.e. the amount of force required to operate them) was clearly too high on the Functional Model. The amount of force required is such that it is difficult to depress them without disturbing the instrument. When firing the laser range-finder this problem is reduced as the laser is fired as the button is released rather than when it is depressed. All the same, the buttons on the final production instrument must be suitably stiff for operation with both bare and gloved hands.

5.3 Tilted Eyepieces

During the development of the Main Module we considered both straight and tilted eyepieces. Traditionally hand-held laser range-finders have had straight eyepieces, whereas tripod-mounted systems have frequently had tilted eyepieces. We decided that there were more advantages than disadvantages with tilted eyepieces for hand-held operation too, and chose that for the Functional Model. We have listed some of the advantages and disadvantages of tilted eyepieces below.

Advantages of tilted eyepieces:

Reduced Neck Strain
In order to reduce both the weight and the visibility of the equipment it is desirable to use a low tripod, which leads to the necessity for the operator to bend down to look through the instrument telescope. Hence with the Main Module tripod-mounted, and even more so with the operator prone and the Main Module hand-held, tilted eyepieces give an ergonomically improved position, as it is not necessary for the operator to bend his neck as much in order to look through the eyepieces.

Easier Operation with a Helmet
During the trials at Älvdalen some simple tests were carried out, where the Main Module was compared with a Simrad LE7 laser, whose external appearance is identical with the LP7, and with the operator using two different Swedish helmets. Whereas a helmet fouled

the LE7 laser because of its straight eyepieces, particularly with the operator prone, there were no problems using a helmet with the Functional Model (see figure 5.1).

Figure 5.1 *Ergonomics: Tilted and straight eyepieces with helmet.*
Left: The functional model with tilted eyepieces.
Right: Laser range-finder (LE7) with straight eyepieces.
Notice the aiming direction in the right image. The operator has difficulties when trying to aim horizontally due to conflict with the helmet.

Easier Use of the Coarse Sight

When using the coarse aiming sight to align the instrument telescope it is advantageous, especially with hand-held operation, to be able to switch between using the coarse sight and the telescope without having to move the instrument or ones head. The tilted eyepieces mean that the operator's head is slightly above the actual instrument, and hence already correctly placed for looking through the coarse sight. Thus it is generally possible to switch between the coarse sight and the telescope with a small eye movement with no need to move ones head. This enables the forward control officer to re-find an object in the telescope image that he has first seen with the naked eye more rapidly and accurately. The coarse sight was tried out at Älvdalen when observing shell impacts. The procedure of first observing the point of impact with the naked eye, then aiming the instrument with the coarse sight, and finally observing the point of impact with the telescope, could be carried out rapidly and easily.

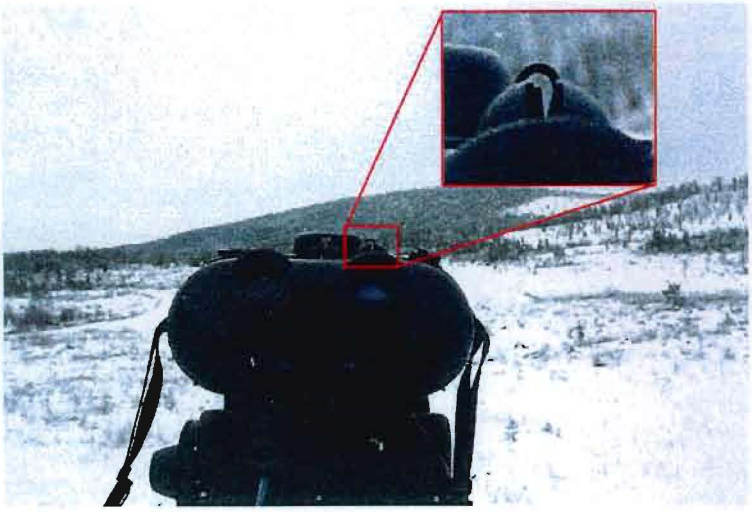

Figure 5.2 The Coarse Sight

Better Support of the Instrument Hand-Held with the Operator Standing
The tilted eyepieces lead to the instrument being held a bit lower than would be the case with straight eyepieces. This leads to the upper arms and elbows being in contact with the operator's chest when standing with the instrument hand-held, and thus better support for the instrument and a more relaxed stance. When sitting it is natural to support ones elbows on ones knees, and thus it makes little difference whether the eyepieces are straight or tilted.

Above we have listed the advantages of tilted eyepieces, but there are also some disadvantages:

Precipitation
Tilted eyepieces mean that precipitation can collect in the eye cups. By having holes in the eye cups it should be possible to ensure that any water runs away. Snow might collect in the eyepieces, however we do not believe that this has been a problem with the tripod-mounted LP3 laser, whose eyepiece is tilted. When the instrument is not in use the eyepieces could be covered by protective caps (the Functional Model does not have protective caps, but the next version of the Main Module will possibly have them).

Focusing of the Sun into the Instrument
In exceptional circumstances with the instrument tripod-mounted there is a risk that the position of the sun and orientation of the instrument could lead to the sun shining directly into the eyepieces. The display eyepiece will then act as a magnifying glass, focusing the sun's rays onto the display, with a risk of damaging it. Should this prove to be a problem, it can be solved by having eye cups that block the light when the instrument is not in use.

5.4 Positioning of Controls and Connectors

During the tests at Älvdalen the temperature lay between -5 and -10 °C. After the instrument had been in use for some time some frost was formed on the goniometer and the underside of the Main Module (see figure 5.3), due to condensation of the operator's breath. Connectors and control knobs and buttons ought to be placed such that there is no risk of them being frozen in place due to frozen condensation.

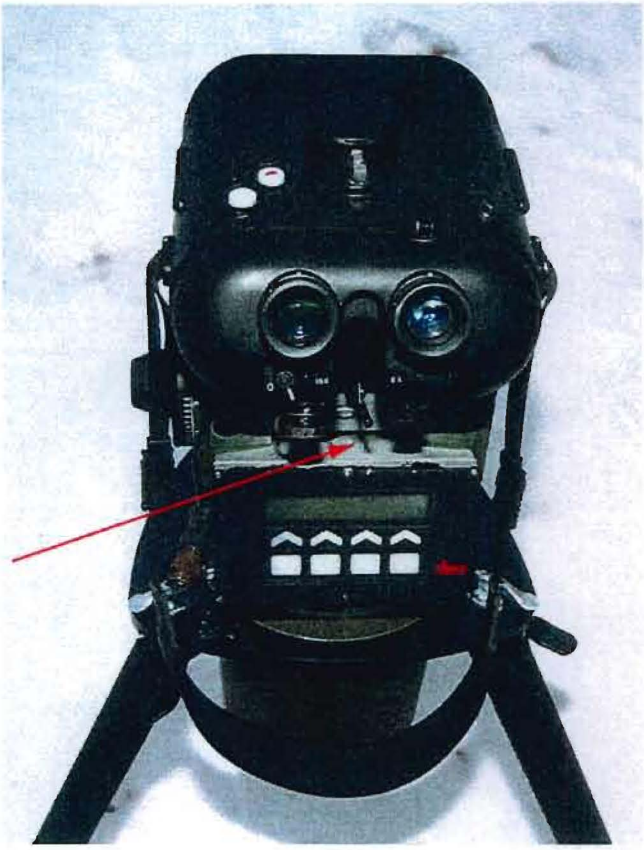

Figure 5.3 The red arrow shows the area where frost was formed due to condensation of the operator's breath.

5.5 Protection of the Optics

In the Functional Model there is no protection of the optics in the form of lens caps etc. The telescope front lens is to some extent protected by the instrument casing projecting beyond the lens. We have, however, been told that the optics must be better protected, or damage is likely. The instrument is likely to be blown over, may be placed unprotected in sacks, etc., so some form of lens protection is necessary.

5.6 Position and Focusing of a Night Vision Module

A night vision module could be placed underneath, on the side or on top of the Main Module. A night vision module mounted on the side of the Main Module would make it difficult to use the instrument hand-held. Placed on top of the Main Module it would screen the GPS antenna. It might be possible to have an extra GPS antenna on the night vision module, to be used when the night vision module was fitted. However, having the night vision module underneath the Main Module would avoid both the above problems.

A mounting bracket was used with the Functional Model for mounting a Simrad Optronics KN200 Clip-On Image Intensifier. A knob on the back of the Clip-On Image Intensifier is used for focusing it, but in hand-held operation the instrument has to be held with one hand only while the image intensifier is focused. This is cumbersome, and if the instrument is to be used hand-held with a night vision module fitted, it ought to be possible to operate the night vision module without having to move ones hands from their normal positions on the Main Module.

6 SUMMARY

As part of FFI Project 697, FA2000, phase 3, sub-project 2: "Forward Observer Instrument" a Functional Model of a forward observer instrument for locating and determining the position of enemy targets has been developed. This report presents the results of user trials of the Functional Model. The instrument, which was completed shortly before the trials, on the whole operated to specification.

The instrument is modular, and consists of a "Main Module", developed jointly by FFI and Simrad Optronics ASA, a goniometer developed by Leica Geosystems AG, and a fibre-optic gyro based north-finder developed by FFI. The Main Module includes an eye-safe laser range-finder, an internal digital magnetic compass, and a GPS receiver. The Main Module can be used hand-held with azimuth determined by the magnetic compass, or tripod-mounted with the north-finder and goniometer giving more accurate azimuth measurement.

During the trials the Main Module was used hand-held, with the operator both standing and sitting, as well as tripod-mounted. After calibrating the magnetic compass correctly the maximum average azimuth error was 8.1 mils. The dispersion of the azimuth measurements about their mean value with the instrument hand-held depends, as one would expect, on how well the instrument is supported, but also on the operator using the instrument. This also applies to the dispersion of the elevation measurements.

With the magnetic compass properly calibrated, it is the uncertainty in magnetic declination, due to local and temporal variations, that is the dominant source of error with the instrument hand-held. The significance of uncertainty in magnetic declination on the accuracy of target position determination is discussed in reference (1).

The standard deviation of the north-finder's north direction determination corresponds well with theoretical performance calculations, based on the performance characteristics of the fibre-optic gyro used in the north-finder. E.g., the standard deviation was 3.2 mils with a north-finding time of three minutes. However, there is some uncertainty concerning how accurately the reference directions used had been surveyed. The surveyed reference directions did not agree with those measured using the Functional Model's north-finder, and the discrepancy was greater than what we have seen when carrying out other measurements using the north-finder. However, as it is possible to correct for a constant azimuth error, it is the dispersion of the measurements about their mean value that is of greatest interest.

Some range-finding measurements were also carried out, but again there was uncertainty about the accuracy of the distances to the reference targets used. The reference distances were established by measuring the target positions using a vehicle fitted with an inertial navigator, which gives a greater uncertainty than what one expects from a laser range-finder. The laser range-finder, however, should have the same accuracy as, e.g., the LP7, which is currently in use in the Norwegian armed forces.

In addition to tests to determine the accuracy of the instrument, some further tests were carried out using the Functional Model: Assessment of the instrument ergonomics, range-finding to shell bursts, assessment of the optics (telescope range tests at both 8× and 15× magnification), and night vision tests with a clip-on image intensifier fitted.

APPENDIX

A MEASUREMENTS WITH THE MAIN MODULE (LP10) - VALUES AND DEVIATIONS

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elevation Average	Elev Dev from average	Date	Time
4	132	1970	892	-	-	-21		-0.4	13.11.98	14:02:16
	133	1990	888	-	-	-20		0.6	13.11.98	14:04:10
	134	1990	886	-	-	-21		-0.4	13.11.98	14:04:53
	135	1990	883	-	-	-20		0.6	13.11.98	14:05:31
	136	1985	886	-	-	-21	-20.6	-0.4	13.11.98	14:06:04
3	137	1635	6255	-	-	-22		-1.6	13.11.98	14:09:47
	138	1635	6250	-	-	-21		-0.6	13.11.98	14:11:27
	139	1635	6251	-	-	-19		1.4	13.11.98	14:12:06
	140	1635	6255	-	-	-20		0.4	13.11.98	14:13:04
	141	1635	6255	-	-	-20	-20.4	0.4	13.11.98	14:13:29
2	142	1370	6254	-	-	-25		0.4	13.11.98	14:14:50
	143	1370	6254	-	-	-26		-0.6	13.11.98	14:15:27
	144	1375	6258	-	-	-25		0.4	13.11.98	14:15:53
	145	1370	6259	-	-	-26		-0.6	13.11.98	14:16:19
	146	1375	6259	-	-	-25	-25.4	0.4	13.11.98	14:16:49
5	147	555	741	-	-	-96		-0.2	13.11.98	14:23:57
	148	555	746	-	-	-96		-0.2	13.11.98	14:24:42
	149	550	744	-	-	-95		0.8	13.11.98	14:25:10
	150	575	743	-	-	-95		0.8	13.11.98	14:25:49
	151	555	746	-	-	-97	-95.8	-1.2	13.11.98	14:26:19
1	152	585	6044	-	-	-84		0.2	13.11.98	14:32:41
	153	585	6043	-	-	-85		-0.8	13.11.98	14:33:47
	154	585	6044	-	-	-83		1.2	13.11.98	14:34:12
	155	585	6047	-	-	-84		0.2	13.11.98	14:34:35
	156	585	6051	-	-	-85	-84.2	-0.8	13.11.98	14:34:59

Table A.1: Tripod mounted. Operator 1. DMC-calibration: 4 point. Focus on rangefinding - no azimuth reference.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	157	525	5705	-	-	-89		-4	13.11.98	14:42:45
1	158	585	5711	-	-	-88		-3	13.11.98	14:43:29
1	159	585	5721	-	-	-90		-5	13.11.98	14:44:10
1	160	585	5740	-	-	-80		5	13.11.98	14:44:53
1	161	580	5734	-	-	-78	-85	7	13.11.98	14:45:23
2	162	1550	5757	-	-	-26		-1.4	13.11.98	14:51:27
2	163	1375	5754	-	-	-20		4.6	13.11.98	14:52:19
2	164	1375	5737	-	-	-19		5.6	13.11.98	14:52:48
2	165	1370	5720	-	-	-25		-0.4	13.11.98	14:53:15
2	166	1375	5693	-	-	-33	-24.6	-8.4	13.11.98	14:53:43
3	167	1725	5713	-	-	-28		-8.2	13.11.98	14:56:17
3	168	1710	5708	-	-	-25		-5.2	13.11.98	14:57:04
3	169	1670	5741	-	-	-20		-0.2	13.11.98	14:57:59
3	170	1725	5723	-	-	-15		4.8	13.11.98	14:58:34
3	171	1600	5757	-	-	-11	-19.8	8.8	13.11.98	14:59:30
4	172	2030	548	-	-	-16		3	13.11.98	15:02:04
4	173	1925	554	-	-	-10		9	13.11.98	15:02:44
4	174	2110	585	-	-	-24		-5	13.11.98	15:03:44
4	175	1985	547	-	-	-18		1	13.11.98	15:05:06
4	176	1925	539	-	-	-27	-19	-8	13.11.98	15:05:49
5	177	550	402	-	-	-98		-1.8	13.11.98	15:07:17
5	178	550	368	-	-	-94		2.2	13.11.98	15:07:56
5	179	540	360	-	-	-94		2.2	13.11.98	15:08:20
5	180	550	365	-	-	-95		1.2	13.11.98	15:10:06
5	181	550	371	-	-	-100	-96.2	-3.8	13.11.98	15:10:49
1	182	585	5490	-	-	-83		1	13.11.98	15:12:13
1	183	585	5486	-	-	-84		0	13.11.98	15:12:37
1	184	580	5510	-	-	-87		-3	13.11.98	15:13:03
1	185	585	5493	-	-	-85		-1	13.11.98	15:13:30
1	186	585	5511	-	-	-81	-84	3	13.11.98	15:14:44

Table A.2: Handheld, standing. Operator 1. DMC-calibration: 4 point. Focus on rangefinding - no azimuth reference.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	187	580	5481	-	-	-81		0.8	13.11.98	15:17:38
1	188	585	5494	-	-	-81		0.8	13.11.98	15:18:17
1	189	585	5480	-	-	-81		0.8	13.11.98	15:18:52
1	190	580	5492	-	-	-84		-2.2	13.11.98	15:19:16
1	191	585	5494	-	-	-82	-81.8	-0.2	13.11.98	15:19:55
2	192	1350	5707	-	-	-28		-2.4	13.11.98	15:21:07
2	193	1375	5713	-	-	-23		2.6	13.11.98	15:21:45
2	194	1355	5709	-	-	-32		-6.4	13.11.98	15:22:35
2	195	1375	5733	-	-	-22		3.6	13.11.98	15:23:05
2	196	1375	5731	-	-	-23	-25.6	2.6	13.11.98	15:23:38
3	197	1620	5711	-	-	-21		0.8	13.11.98	15:24:28
3	198	1620	5687	-	-	-25		-3.2	13.11.98	15:39:30
3	199	1635	5677	-	-	-25		-3.2	13.11.98	15:39:57
3	200	1635	5693	-	-	-21		0.8	13.11.98	15:40:21
3	201	1635	5706	-	-	-17	-21.8	4.8	13.11.98	15:40:49
4	202	1985	453	-	-	-20		-0.2	13.11.98	15:43:20
4	203	1985	451	-	-	-25		-5.2	13.11.98	15:43:43
4	204	2125	456	-	-	-17		2.8	13.11.98	15:44:12
4	205	1930	462	-	-	-19		0.8	13.11.98	15:44:52
4	206	2055	457	-	-	-18	-19.8	1.8	13.11.98	15:45:24
5	207	540	297	-	-	-101		-3.8	13.11.98	15:46:12
5	208	550	311	-	-	-104		-6.8	13.11.98	15:46:51
5	209	550	295	-	-	-91		6.2	13.11.98	15:47:14
5	210	550	293	-	-	-96		1.2	13.11.98	15:47:36
5	211	550	304	-	-	-94	-97.2	3.2	13.11.98	15:47:55

Table A.3: Handheld, sitting. Operator 1. DMC-calibration: 4 point. Focus on rangefinding - no azimuth reference.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	236	155	20	-21.7		40		-0.2	15.11.98	10:39:38
1	237	155	33	-8.7		41		0.8	15.11.98	10:41:01
1	238	165	22	-19.7		43		2.8	15.11.98	10:41:33
1	239	160	19	-22.7		39		-1.2	15.11.98	10:41:51
1	240	160	21	-20.7	-18.7	38	40.2	-2.2	15.11.98	10:42:11
2	241	170	627	-37.4		36		2.6	15.11.98	10:42:46
2	242	175	625	-39.4		35		1.6	15.11.98	10:43:10
2	243	175	622	-42.4		35		1.6	15.11.98	10:43:30
2	244	175	621	-43.4		32		-1.4	15.11.98	10:43:50
2	245	175	637	-27.4	-38	29	33.4	-4.4	15.11.98	10:44:08
3	246	300	957	-47.7		59		-0.8	15.11.98	10:44:42
3	247	295	967	-37.7		61		1.2	15.11.98	10:45:02
3	248	295	965	-39.7		63		3.2	15.11.98	10:45:26
3	249	280	954	-50.7		65		5.2	15.11.98	10:45:52
3	250	300	967	-37.7	-42.7	51	59.8	-8.8	15.11.98	10:46:11
4	251	85	2257	-59.2		-27		-3	15.11.98	10:46:54
4	252	105	2252	-64.2		-25		-1	15.11.98	10:47:23
4	253	90	2243	-73.2		-24		0	15.11.98	10:47:56
4	254	105	2239	-77.2		-17		7	15.11.98	10:48:18
4	255	85	2258	-58.2	-66.4	-27	-24	-3	15.11.98	10:48:40
5	256	380	3328	-73.1		1		-1	15.11.98	10:49:09
5	257	430	3329	-72.1		2		0	15.11.98	10:49:31
5	258	380	3316	-85.1		7		5	15.11.98	10:49:50
5	259	380	3316	-85.1		3		1	15.11.98	10:50:12
5	260	380	3317	-84.1	-79.9	-3	2	-5	15.11.98	10:50:28
6	261	440	3555	-88.9		9		1.2	15.11.98	10:51:05
6	262	435	3570	-73.9		9		1.2	15.11.98	10:51:30
6	263	430	3558	-85.9		9		1.2	15.11.98	10:51:47
6	264	430	3551	-92.9		8		0.2	15.11.98	10:52:02
6	265	435	3547	-96.9	-87.7	4	7.8	-3.8	15.11.98	10:52:19
7	266	625	4174	-64.2		77		0.6	15.11.98	10:53:56
7	267	655	4163	-75.2		76		-0.4	15.11.98	10:54:17
7	268	625	4162	-76.2		75		-1.4	15.11.98	10:54:40
7	269	625	4171	-67.2		77		0.6	15.11.98	10:54:58
7	270	625	4168	-70.2	-70.6	77	76.4	0.6	15.11.98	10:55:16
8	271	80	5326	-7.3		-86		-0.4	15.11.98	10:55:56
8	272	75	5329	-4.3		-84		1.6	15.11.98	10:56:17
8	273	70	5331	-2.3		-87		-1.4	15.11.98	10:56:37
8	274	80	5328	-5.3		-88		-2.4	15.11.98	10:56:56
8	275	75	5338	4.7	-2.9	-83	-85.6	2.6	15.11.98	10:57:15

Table A.4: Handheld stående. Operator 2 (without webbing). DMC-calibration: 4 point. Measurements carried out without batteries in the main module.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	276	160	23	-18.7		45		0.4	15.11.98	11:22:32
1	277	160	19	-22.7		46		1.4	15.11.98	11:22:53
1	278	160	23	-18.7		45		0.4	15.11.98	11:23:12
1	279	155	27	-14.7		41		-3.6	15.11.98	11:23:28
1	280	160	29	-12.7	-17.5	46	44.6	1.4	15.11.98	11:23:51
2	281	175	643	-21.4		40		1.4	15.11.98	11:24:39
2	282	175	637	-27.4		36		-2.6	15.11.98	11:25:03
2	283	175	633	-31.4		39		0.4	15.11.98	11:25:21
2	284	175	632	-32.4		40		1.4	15.11.98	11:25:57
2	285	175	638	-26.4	-27.8	38	38.6	-0.6	15.11.98	11:26:15
3	286	295	969	-35.7		65		-1.8	15.11.98	11:26:49
3	287	300	963	-41.7		68		1.2	15.11.98	11:27:05
3	288	300	966	-38.7		68		1.2	15.11.98	11:27:27
3	289	295	971	-33.7		66		-0.8	15.11.98	11:27:43
3	290	295	964	-40.7	-38.1	67	66.8	0.2	15.11.98	11:28:00
4	291	90	2251	-65.2		-12		1.6	15.11.98	11:28:46
4	292	85	2254	-62.2		-13		0.6	15.11.98	11:29:16
4	293	110	2259	-57.2		-15		-1.4	15.11.98	11:29:35
4	294	90	2255	-61.2		-14		-0.4	15.11.98	11:29:54
4	295	105	2254	-62.2	-61.6	-14	-13.6	-0.4	15.11.98	11:30:23
5	296	405	3320	-81.1		9		0.4	15.11.98	11:31:17
5	297	410	3320	-81.1		9		0.4	15.11.98	11:31:42
5	298	405	3321	-80.1		9		0.4	15.11.98	11:32:03
5	299	375	3317	-84.1		9		0.4	15.11.98	11:32:19
5	300	380	3319	-82.1	-81.7	7	8.6	-1.6	15.11.98	11:32:36
6	301	435	3566	-77.9		13		1.2	15.11.98	11:33:36
6	302	435	3568	-75.9		11		-0.8	15.11.98	11:33:56
6	303	435	3562	-81.9		12		0.2	15.11.98	11:34:15
6	304	435	3568	-75.9		14		2.2	15.11.98	11:34:31
6	305	430	3564	-79.9	-78.3	9	11.8	-2.8	15.11.98	11:34:48
7	306	630	4174	-64.2		80		0.2	15.11.98	11:35:43
7	307	625	4182	-56.2		83		3.2	15.11.98	11:36:02
7	308	625	4172	-66.2		77		-2.8	15.11.98	11:36:25
7	309	625	4180	-58.2		79		-0.8	15.11.98	11:36:40
7	310	630	4176	-62.2	-61.4	80	79.8	0.2	15.11.98	11:36:58
8	311	75	5332	-1.3		-73		-0.4	15.11.98	11:38:24
8	312	75	5333	-0.3		-72		0.6	15.11.98	11:38:44
8	313	70	5337	3.7		-72		0.6	15.11.98	11:39:06
8	314	75	5330	-3.3		-75		-2.4	15.11.98	11:39:26
8	315	75	5337	3.7	0.5	-71	-72.6	1.6	15.11.98	11:39:41

Table A.5: Handheld sitting. Operator 2 (without webbing). DMC-calibration: 4 point. Measurements carried out without batteries in the main module.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	316	155	37	-4.7		41		-3.4	15.11.98	13:18:46
1	317	160	40	-1.7		46		1.6	15.11.98	13:19:12
1	318	155	43	1.3		46		1.6	15.11.98	13:19:27
1	319	155	40	-1.7		43		-1.4	15.11.98	13:19:52
1	320	160	43	1.3	-1.1	46	44.4	1.6	15.11.98	13:20:08
2	321	100	644	-20.4		43		2.6	15.11.98	13:21:20
2	322	95	646	-18.4		38		-2.4	15.11.98	13:21:44
2	323	100	650	-14.4		40		-0.4	15.11.98	13:22:19
2	324	100	650	-14.4		40		-0.4	15.11.98	13:22:36
2	325	100	649	-15.4	-16.6	41	40.4	0.6	15.11.98	13:23:05
3	326	300	982	-22.7		67		2.6	15.11.98	13:23:27
3	327	300	996	-8.7		62		-2.4	15.11.98	13:23:47
3	328	295	991	-13.7		63		-1.4	15.11.98	13:24:07
3	329	300	989	-15.7		62		-2.4	15.11.98	13:24:24
3	330	300	977	-27.7	-17.7	68	64.4	3.6	15.11.98	13:24:40
4	331	110	2255	-61.2		-9		2	15.11.98	13:25:39
4	332	110	2262	-54.2		-13		-2	15.11.98	13:26:04
4	333	105	2268	-48.2		-15		-4	15.11.98	13:26:24
4	334	110	2253	-63.2		-10		1	15.11.98	13:26:39
4	335	110	2253	-63.2	-58	-8	-11	3	15.11.98	13:26:58
5	336	405	3311	-90.1		8		0.6	15.11.98	13:27:33
5	337	405	3307	-94.1		6		-1.4	15.11.98	13:27:52
5	338	410	3306	-95.1		7		-0.4	15.11.98	13:28:28
5	339	405	3309	-92.1		9		1.6	15.11.98	13:28:44
5	340	405	3313	-88.1	-91.9	7	7.4	-0.4	15.11.98	13:29:10
6	341	435	3556	-87.9		11		0.6	15.11.98	13:29:41
6	342	435	3552	-91.9		10		-0.4	15.11.98	13:30:19
6	343	435	3553	-90.9		10		-0.4	15.11.98	13:30:39
6	344	435	3553	-90.9		10		-0.4	15.11.98	13:30:56
6	345	435	3557	-86.9	-89.7	11	10.4	0.6	15.11.98	13:31:18
7	346	660	4164	-74.2		83		2	15.11.98	13:31:57
7	347	630	4163	-75.2		81		0	15.11.98	13:32:19
7	348	655	4159	-79.2		80		-1	15.11.98	13:32:35
7	349	625	4163	-75.2		83		2	15.11.98	13:33:00
7	350	625	4157	-81.2	-77	78	81	-3	15.11.98	13:33:16
8	351	75	5331	-2.3		-73		0.2	15.11.98	13:33:52
8	352	75	5324	-9.3		-74		-0.8	15.11.98	13:34:10
8	353	75	5326	-7.3		-75		-1.8	15.11.98	13:34:26
8	354	75	5326	-7.3		-73		0.2	15.11.98	13:34:42
8	355	75	5331	-2.3	-5.7	-71	-73.2	2.2	15.11.98	13:34:59

Table A.6: Handheld sitting. Operator 2 (without webbing). DMC-calibration: 4 point. Measurements carried out with batteries in the main module.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	356	155	41	-0.7		45		1.2	15.11.98	13:44:14
1	357	165	37	-4.7		46		2.2	15.11.98	13:44:40
1	358	155	38	-3.7		42		-1.8	15.11.98	13:44:57
1	359	160	36	-5.7		42		-1.8	15.11.98	13:45:22
1	360	160	39	-2.7	-3.5	44	43.8	0.2	15.11.98	13:45:42
2	361	100	644	-20.4		39		-0.8	15.11.98	13:46:23
2	362	105	644	-20.4		42		2.2	15.11.98	13:46:49
2	363	100	657	-7.4		37		-2.8	15.11.98	13:47:05
2	364	100	644	-20.4		40		0.2	15.11.98	13:47:24
2	365	95	648	-16.4	-17	41	39.8	1.2	15.11.98	13:47:57
3	366	300	985	-19.7		67		1.8	15.11.98	13:48:20
3	367	300	993	-11.7		65		-0.2	15.11.98	13:48:41
3	368	300	993	-11.7		64		-1.2	15.11.98	13:48:54
3	369	300	988	-16.7		64		-1.2	15.11.98	13:49:14
3	370	295	985	-19.7	-15.9	66	65.2	0.8	15.11.98	13:49:32
4	371	110	2283	-33.2		-14		-1.2	15.11.98	13:49:57
4	372	90	2272	-44.2		-11		1.8	15.11.98	13:50:16
4	373	105	2272	-44.2		-10		2.8	15.11.98	13:50:36
4	374	105	2282	-34.2		-16		-3.2	15.11.98	13:50:50
4	375	110	2280	-36.2	-38.4	-13	-12.8	-0.2	15.11.98	13:51:08
5	376	385	3331	-70.1		9		1.8	15.11.98	13:51:36
5	377	380	3322	-79.1		8		0.8	15.11.98	13:51:59
5	378	380	3330	-71.1		5		-2.2	15.11.98	13:52:12
5	379	370	3322	-79.1		7		-0.2	15.11.98	13:52:32
5	380	405	3333	-68.1	-73.5	7	7.2	-0.2	15.11.98	13:53:12
6	381	440	3566	-77.9		12		0.4	15.11.98	13:53:44
6	382	435	3566	-77.9		12		0.4	15.11.98	13:54:19
6	383	440	3576	-67.9		11		-0.6	15.11.98	13:54:41
6	384	435	3573	-70.9		11		-0.6	15.11.98	13:54:57
6	385	435	3569	-74.9	-73.9	12	11.6	0.4	15.11.98	13:55:16
7	386	630	4176	-62.2		81		0.4	15.11.98	13:55:43
7	387	625	4171	-67.2		81		0.4	15.11.98	13:56:02
7	388	630	4172	-66.2		81		0.4	15.11.98	13:56:32
7	389	625	4167	-71.2		80		-0.6	15.11.98	13:56:52
7	390	625	4173	-65.2	-66.4	80	80.6	-0.6	15.11.98	13:57:23
8	391	75	5332	-1.3		-72		0.4	15.11.98	13:58:03
8	392	75	5334	0.7		-72		0.4	15.11.98	13:58:20
8	393	75	5328	-5.3		-72		0.4	15.11.98	13:58:43
8	394	75	5331	-2.3		-71		1.4	15.11.98	13:59:08
8	395	80	5321	-12.3	-4.1	-75	-72.4	-2.6	15.11.98	13:59:39

Table A.7: Handheld, sitting. Operator 2 (with webbing). DMC-calibration: 4 point. Measurements carried out with batteries in the main module.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	396	160	33	-8.7		43		-1.2	15.11.98	14:12:50
1	397	160	31	-10.7		45		0.8	15.11.98	14:13:24
1	398	155	34	-7.7		44		-0.2	15.11.98	14:13:49
1	399	160	33	-8.7		45		0.8	15.11.98	14:14:10
1	400	160	34	-7.7	-8.7	44	44.2	-0.2	15.11.98	14:14:30
2	401	180	651	-13.4		39		0.2	15.11.98	14:15:45
2	402	180	647	-17.4		38		-0.8	15.11.98	14:16:03
2	403	175	646	-18.4		39		0.2	15.11.98	14:16:20
2	404	180	645	-19.4		39		0.2	15.11.98	14:16:36
2	405	175	647	-17.4	-17.2	39	38.8	0.2	15.11.98	14:16:49
3	406	300	997	-7.7		65		1	15.11.98	14:17:37
3	407	0	998	-6.7		64		0	15.11.98	14:18:38
3	408	0	998	-6.7		64		0	15.11.98	14:19:01
3	409	0	1000	-4.7		63		-1	15.11.98	14:19:14
3	410	0	1001	-3.7	-5.9	64	64	0	15.11.98	14:19:41
4	411	0	2302	-14.2		-15		-0.8	15.11.98	14:20:27
4	412	0	2298	-18.2		-14		0.2	15.11.98	14:20:50
4	413	0	2297	-19.2		-14		0.2	15.11.98	14:21:04
4	414	0	2299	-17.2		-14		0.2	15.11.98	14:21:22
4	415	0	2296	-20.2	-17.8	-14	-14.2	0.2	15.11.98	14:21:39
5	416	0	3355	-46.1		6		-0.6	15.11.98	14:22:42
5	417	0	3355	-46.1		8		1.4	15.11.98	14:22:57
5	418	0	3356	-45.1		6		-0.6	15.11.98	14:23:11
5	419	0	3357	-44.1		7		0.4	15.11.98	14:23:25
5	420	0	3354	-47.1	-45.7	6	6.6	-0.6	15.11.98	14:23:38
6	421	0	3598	-45.9		11		0.4	15.11.98	14:24:06
6	422	0	3595	-48.9		11		0.4	15.11.98	14:24:23
6	423	0	3596	-47.9		10		-0.6	15.11.98	14:24:39
6	424	0	3594	-49.9		10		-0.6	15.11.98	14:24:51
6	425	0	3597	-46.9	-47.9	11	10.6	0.4	15.11.98	14:25:04
7	426	0	4195	-43.2		81		0	15.11.98	14:25:54
7	427	0	4195	-43.2		81		0	15.11.98	14:26:09
7	428	0	4198	-40.2		82		1	15.11.98	14:26:22
7	429	0	4195	-43.2		81		0	15.11.98	14:26:35
7	430	0	4191	-47.2	-43.4	80	81	-1	15.11.98	14:26:50
8	431	0	5325	-8.3		-75		0.2	15.11.98	14:27:58
8	432	0	5327	-6.3		-75		0.2	15.11.98	14:28:17
8	433	0	5330	-3.3		-75		0.2	15.11.98	14:28:30
8	434	0	5324	-9.3		-76		-0.8	15.11.98	14:28:45
8	435	0	5329	-4.3	-6.3	-75	-75.2	0.2	15.11.98	14:29:00

Table A.8: Tripod mounted. Operator 2 (without webbing). DMC-calibration: 4 point. Measurements carried out with batteries in the main module.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	502	0	33	-8.7		53		6.6	16.11.98	12:39:40
1	503	0	46	4.3		43		-3.4	16.11.98	12:40:22
1	504	0	37	-4.7		45		-1.4	16.11.98	12:40:56
1	505	0	33	-8.7		45		-1.4	16.11.98	12:41:17
1	506	0	34	-7.7	-5.1	46	46.4	-0.4	16.11.98	12:41:36
2	507	0	657	-7.4		40		-0.2	16.11.98	12:42:14
2	508	0	662	-2.4		39		-1.2	16.11.98	12:42:34
2	509	0	656	-8.4		41		0.8	16.11.98	12:42:52
2	510	0	657	-7.4		41		0.8	16.11.98	12:43:11
2	511	0	660	-4.4	-6	40	40.2	-0.2	16.11.98	12:43:31
3	512	0	997	-7.7		67		1.6	16.11.98	12:44:23
3	513	0	995	-9.7		67		1.6	16.11.98	12:44:53
3	514	0	1006	1.3		63		-2.4	16.11.98	12:45:19
3	515	0	1000	-4.7		65		-0.4	16.11.98	12:45:38
3	516	0	1001	-3.7	-4.9	65	65.4	-0.4	16.11.98	12:46:04
4	517	0	2326	9.8		-14		-0.2	16.11.98	12:47:51
4	518	0	2327	10.8		-14		-0.2	16.11.98	12:48:15
4	519	0	2323	6.8		-15		-1.2	16.11.98	12:48:33
4	520	0	2322	5.8		-14		-0.2	16.11.98	12:49:01
4	521	0	2316	-0.2	6.6	-12	-13.8	1.8	16.11.98	12:49:39
5	522	0	3405	3.9		7		-0.4	16.11.98	12:50:19
5	523	0	3413	11.9		8		0.6	16.11.98	12:50:47
5	524	0	3411	9.9		8		0.6	16.11.98	12:51:15
5	525	0	3409	7.9		7		-0.4	16.11.98	12:51:36
5	526	0	3408	6.9	8.1	7	7.4	-0.4	16.11.98	12:51:57
6	527	0	3646	2.1		9		-1.4	16.11.98	12:52:55
6	528	0	3658	14.1		12		1.6	16.11.98	12:53:15
6	529	0	3655	11.1		12		1.6	16.11.98	12:53:35
6	530	0	3654	10.1		10		-0.4	16.11.98	12:53:56
6	531	0	3643	-0.9	7.3	9	10.4	-1.4	16.11.98	12:54:22
7	532	0	4242	3.8		80		1.2	16.11.98	12:54:50
7	533	0	4243	4.8		79		0.2	16.11.98	12:55:09
7	534	0	4240	1.8		79		0.2	16.11.98	12:55:32
7	535	0	4245	6.8		79		0.2	16.11.98	12:55:52
7	536	0	4234	-4.2	2.6	77	78.8	-1.8	16.11.98	12:56:12
8	537	0	5338	4.7		-73		0.8	16.11.98	12:56:56
8	538	0	5334	0.7		-74		-0.2	16.11.98	12:57:16
8	539	0	5330	-3.3		-75		-1.2	16.11.98	12:57:35
8	540	0	5335	1.7		-75		-1.2	16.11.98	12:57:55
8	541	0	5340	6.7	2.1	-72	-73.8	1.8	16.11.98	12:58:13
9	542	0	4067	-3.9		90		0.4	16.11.98	12:58:45
9	543	0	4072	1.1		90		0.4	16.11.98	12:59:20
9	544	0	4073	2.1		87		-2.6	16.11.98	12:59:58
9	545	0	4074	3.1		92		2.4	16.11.98	13:00:18
9	546	0	4072	1.1	0.7	89	89.6	-0.6	16.11.98	13:00:36

Table A.9: Handheld sitting. Operator 2. DMC-calibration: 12 point.

Target no	Measurement no	Range	Azimuth	Azimuth Deviation	Azimuth Average deviation	Elev	Elev Average	Elev Dev from average	Date	Time
1	547	0	46	4.3		36		0.4	16.11.98	13:05:34
1	548	0	40	-1.7		37		1.4	16.11.98	13:05:56
1	549	0	41	-0.7		36		0.4	16.11.98	13:06:31
1	550	0	36	-5.7		33		-2.6	16.11.98	13:06:57
1	551	0	34	-7.7	-2.3	36	35.6	0.4	16.11.98	13:07:13
2	552	0	663	-1.4		36		2	16.11.98	13:07:42
2	553	0	659	-5.4		33		-1	16.11.98	13:08:04
2	554	0	654	-10.4		34		0	16.11.98	13:08:42
2	555	0	661	-3.4		35		1	16.11.98	13:09:02
2	556	0	660	-4.4	-5	32	34	-2	16.11.98	13:09:26
3	557	0	991	-13.7		65		4.2	16.11.98	13:10:17
3	558	0	1008	3.3		58		-2.8	16.11.98	13:10:38
3	559	0	994	-10.7		65		4.2	16.11.98	13:11:02
3	560	0	1014	9.3		58		-2.8	16.11.98	13:11:21
3	561	0	1010	5.3	-1.3	58	60.8	-2.8	16.11.98	13:11:43
4	562	0	2317	0.8		-26		-1.4	16.11.98	13:12:14
4	563	0	2300	-16.2		-19		5.6	16.11.98	13:12:36
4	564	0	2329	12.8		-26		-1.4	16.11.98	13:12:56
4	565	0	2320	3.8		-26		-1.4	16.11.98	13:13:17
4	566	0	2325	8.8	2	-26	-24.6	-1.4	16.11.98	13:13:35
5	567	0	3401	-0.1		4		0.6	16.11.98	13:16:33
5	568	0	3396	-5.1		5		1.6	16.11.98	13:16:59
5	569	0	3406	4.9		3		-0.4	16.11.98	13:17:23
5	570	0	3401	-0.1		3		-0.4	16.11.98	13:17:48
5	571	0	3391	-10.1	-2.1	2	3.4	-1.4	16.11.98	13:18:10
6	572	0	3647	3.1		6		-0.8	16.11.98	13:18:40
6	573	0	3633	-10.9		3		-3.8	16.11.98	13:18:58
6	574	0	3647	3.1		11		4.2	16.11.98	13:19:20
6	575	0	3640	-3.9		8		1.2	16.11.98	13:19:38
6	576	0	3643	-0.9	-1.9	6	6.8	-0.8	16.11.98	13:19:58
7	577	0	4229	-9.2		72		-3.2	16.11.98	13:22:03
7	578	0	4237	-1.2		75		-0.2	16.11.98	13:22:24
7	579	0	4246	7.8		76		0.8	16.11.98	13:22:47
7	580	0	4237	-1.2		78		2.8	16.11.98	13:23:09
7	581	0	4240	1.8	-0.4	75	75.2	-0.2	16.11.98	13:23:29
8	582	0	5345	11.7		-81		1.8	16.11.98	13:23:51
8	583	0	5331	-2.3		-84		-1.2	16.11.98	13:24:08
8	584	0	5354	20.7		-80		2.8	16.11.98	13:24:27
8	585	0	5331	-2.3		-87		-4.2	16.11.98	13:24:48
8	586	0	5346	12.7	8.1	-82	-82.8	0.8	16.11.98	13:25:06
9	587	0	4078	7.1		91		0	16.11.98	13:25:48
9	588	0	4077	6.1		92		1	16.11.98	13:26:10
9	589	0	4080	9.1	7.4	90	91	-1	16.11.98	13:26:32

Table A.10: Handheld standing. Operator 2. DMC-calibration: 12 point.

B POSITION OF THE INSTRUMENT AND CALCULATED TARGET POSITION FOR EVERY MEASUREMENT

Positions are calculated in the main module (UTM WGS84, UTM-zone:33V).

Measurement no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
132	432490.0	6818089.0	635.3	434002.0	6819349.8	595.0	On
133	432454.0	6817975.0	682.5	433976.3	6819254.7	643.7	On
134	432484.0	6818108.0	759.8	434003.8	6819390.6	719.0	On
135	432481.0	6818091.0	776.2	433997.0	6819378.1	737.4	On
136	432491.0	6818096.0	811.6	434006.9	6819375.4	770.9	On
137	432507.0	6818061.0	675.0	432275.2	6819678.4	639.9	Off
138	432507.0	6818061.0	675.0	432267.2	6819677.2	641.5	Off
139	432507.0	6818061.0	675.0	432268.8	6819677.5	644.7	Off
140	432507.0	6818061.0	675.0	432275.2	6819678.4	643.1	Off
141	432507.0	6818061.0	675.0	432275.2	6819678.4	643.1	Off
142	432507.0	6818061.0	675.0	432311.4	6819415.9	641.5	Off
143	432507.0	6818061.0	675.0	432311.4	6819415.9	640.2	Off
144	432507.0	6818061.0	675.0	432316.1	6819421.6	641.4	Off
145	432507.0	6818061.0	675.0	432318.1	6819416.8	640.2	Off
146	432507.0	6818061.0	675.0	432317.4	6819421.8	641.4	Off
147	432507.0	6818061.0	675.0	432874.3	6818473.5	622.8	Off
148	432507.0	6818061.0	675.0	432876.3	6818471.7	622.8	Off
149	432507.0	6818061.0	675.0	432872.2	6818468.7	623.8	Off
150	432507.0	6818061.0	675.0	432888.4	6818487.6	621.5	Off
151	432507.0	6818061.0	675.0	432876.2	6818471.6	622.2	Off
152	432507.0	6818061.0	675.0	432307.4	6818608.5	626.8	Off
153	432507.0	6818061.0	675.0	432306.9	6818608.3	626.3	Off
154	432507.0	6818061.0	675.0	432307.4	6818608.6	627.4	Off
155	432507.0	6818061.0	675.0	432309.1	6818609.1	626.8	Off
156	432507.0	6818061.0	675.0	432311.2	6818609.8	626.3	Off
157	432507.0	6818061.0	675.0	432177.3	6818466.7	629.2	Off
158	432507.0	6818061.0	675.0	432142.3	6818515.3	624.5	Off
159	432507.0	6818061.0	675.0	432146.9	6818518.8	623.4	Off
160	432507.0	6818061.0	675.0	432155.2	6818525.8	629.1	Off
161	432507.0	6818061.0	675.0	432155.4	6818519.8	630.7	Off
162	432507.0	6818061.0	675.0	431592.9	6819311.3	635.6	Off
163	432507.0	6818061.0	675.0	431692.8	6819167.9	648.1	Off
164	432507.0	6818061.0	675.0	431674.4	6819154.2	649.5	Off
165	432507.0	6818061.0	675.0	431659.5	6819136.1	641.5	Off
166	432507.0	6818061.0	675.0	431628.3	6819116.8	630.6	Off
167	432507.0	6818061.0	675.0	431430.7	6819407.2	627.8	Off
168	432507.0	6818061.0	675.0	431433.4	6819390.3	633.2	Off
169	432507.0	6818061.0	675.0	431501.0	6819392.7	642.4	Off
170	432507.0	6818061.0	675.0	431443.6	6819418.0	649.8	Off
171	432507.0	6818061.0	675.0	431563.2	6819352.0	657.9	Off
172	432507.0	6818061.0	675.0	433546.6	6819803.2	643.4	Off
173	432507.0	6818061.0	675.0	433502.6	6819707.4	656.4	Off
174	432507.0	6818061.0	675.0	433652.5	6819831.2	625.6	Off
175	432507.0	6818061.0	675.0	433521.9	6819765.6	640.2	Off
176	432507.0	6818061.0	675.0	433478.0	6819721.4	624.2	Off
177	432507.0	6818061.0	675.0	432717.4	6818566.1	622.2	Off
178	432507.0	6818061.0	675.0	432700.5	6818573.1	624.3	Off
179	432507.0	6818061.0	675.0	432693.0	6818565.2	625.3	Off

Measure ment no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
180	432507.0	6818061.0	675.0	432699.0	6818573.6	623.8	Off
181	432507.0	6818061.0	675.0	432701.9	6818572.2	621.1	Off
182	432507.0	6818061.0	675.0	432052.9	6818426.3	627.4	Off
183	432507.0	6818061.0	675.0	432051.5	6818424.5	626.8	Off
184	432507.0	6818061.0	675.0	432064.1	6818431.8	625.5	Off
185	432507.0	6818061.0	675.0	432054.0	6818427.6	626.3	Off
186	432507.0	6818061.0	675.0	432060.4	6818435.6	628.6	Off
187	432507.0	6818061.0	675.0	432053.5	6818419.2	628.9	Off
188	432507.0	6818061.0	675.0	432054.2	6818428.1	628.6	Off
189	432507.0	6818061.0	675.0	432049.2	6818421.9	628.6	Off
190	432507.0	6818061.0	675.0	432057.5	6818424.0	627.2	Off
191	432507.0	6818061.0	675.0	432054.3	6818428.1	628.0	Off
192	432507.0	6818061.0	675.0	431658.5	6819109.6	638.0	Off
193	432507.0	6818061.0	675.0	431648.9	6819134.2	644.1	Off
194	432507.0	6818061.0	675.0	431657.5	6819115.0	632.6	Off
195	432507.0	6818061.0	675.0	431670.2	6819150.8	645.4	Off
196	432507.0	6818061.0	675.0	431668.0	6819149.2	644.1	Off
197	432507.0	6818061.0	675.0	431493.5	6819323.5	641.8	Off
198	432507.0	6818061.0	675.0	431464.2	6819299.1	635.4	Off
199	432507.0	6818061.0	675.0	431442.3	6819300.2	635.1	Off
200	432507.0	6818061.0	675.0	431461.8	6819316.9	641.5	Off
201	432507.0	6818061.0	675.0	431477.8	6819330.2	647.9	Off
202	432507.0	6818061.0	675.0	433360.4	6819851.8	636.3	Off
203	432507.0	6818061.0	675.0	433356.8	6819853.2	626.6	Off
204	432507.0	6818061.0	675.0	433426.3	6819975.5	639.8	Off
205	432507.0	6818061.0	675.0	433352.1	6819794.8	639.3	Off
206	432507.0	6818061.0	675.0	433397.8	6819911.5	639.0	Off
207	432507.0	6818061.0	675.0	432661.4	6818575.4	621.6	Off
208	432507.0	6818061.0	675.0	432671.4	6818582.6	619.0	Off
209	432507.0	6818061.0	675.0	432663.4	6818585.8	625.9	Off
210	432507.0	6818061.0	675.0	432662.3	6818585.8	623.3	Off
211	432507.0	6818061.0	675.0	432668.0	6818584.2	624.3	Off
216	432531.0	6824555.0	568.6	439170.7	6824241.9	552.0	Off
217	432531.0	6824555.0	568.6	439166.0	6824248.6	552.0	Off
218	432531.0	6824555.0	568.6	439166.3	6824255.2	552.0	Off
219	432531.0	6824555.0	568.6	439161.9	6824268.4	552.0	Off
220	432531.0	6824555.0	568.6	439167.7	6824287.7	558.6	Off
221	432531.0	6824555.0	568.6	439170.0	6824352.9	552.0	Off
222	432531.0	6824555.0	568.6	439168.9	6824320.3	539.0	Off
223	432531.0	6824555.0	568.6	439171.3	6824398.5	558.6	Off
224	432531.0	6824555.0	568.6	439171.6	6824411.6	565.1	Off
225	432543.0	6824534.0	720.0	439182.4	6824351.5	696.9	Off
230	432646.0	6824501.0	796.7	439281.8	6824383.7	773.6	On
231	432616.0	6824502.0	783.6	439252.6	6824443.4	773.5	On
232	432590.0	6824503.0	765.0	439236.8	6824457.3	761.5	On
233	432563.0	6824507.0	730.7	438624.5	6824417.7	715.3	On
234	432561.0	6824522.0	702.1	439202.3	6824430.7	692.1	On
236	435620.0	6807779.0	191.7	435623.0	6807933.8	197.8	Off
237	435620.0	6807779.0	191.7	435625.0	6807933.7	198.0	Off
238	435620.0	6807779.0	191.7	435623.6	6807943.8	198.7	Off

Measurement no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
239	435620.0	6807779.0	191.7	435623.0	6807938.8	197.9	Off
240	435620.0	6807779.0	191.7	435623.3	6807938.8	197.7	Off
241	435620.0	6807779.0	191.7	435718.1	6807917.7	197.8	Off
242	435620.0	6807779.0	191.7	435720.7	6807921.9	197.8	Off
243	435620.0	6807779.0	191.7	435720.2	6807922.2	197.8	Off
244	435620.0	6807779.0	191.7	435720.1	6807922.3	197.2	Off
245	435620.0	6807779.0	191.7	435722.4	6807920.8	196.7	Off
246	435620.0	6807779.0	191.7	435861.7	6807955.7	209.1	Off
247	435620.0	6807779.0	191.7	435859.3	6807950.4	209.4	Off
248	435620.0	6807779.0	191.7	435859.0	6807950.8	210.0	Off
249	435620.0	6807779.0	191.7	435845.0	6807944.5	209.6	Off
250	435620.0	6807779.0	191.7	435863.5	6807953.4	206.8	Off
251	435620.0	6807779.0	191.7	435687.9	6807727.9	189.5	Off
252	435620.0	6807779.0	191.7	435704.2	6807716.3	189.2	Off
253	435620.0	6807779.0	191.7	435692.6	6807725.9	189.6	Off
254	435620.0	6807779.0	191.7	435705.0	6807717.4	190.0	Off
255	435620.0	6807779.0	191.7	435687.8	6807727.9	189.5	Off
256	435620.0	6807779.0	191.7	435572.4	6807402.1	192.1	Off
257	435620.0	6807779.0	191.7	435565.7	6807352.6	192.6	Off
258	435620.0	6807779.0	191.7	435576.8	6807401.6	194.4	Off
259	435620.0	6807779.0	191.7	435576.8	6807401.6	192.9	Off
260	435620.0	6807779.0	191.7	435576.5	6807401.6	190.6	Off
261	435620.0	6807779.0	191.7	435469.8	6807365.6	195.6	Off
262	435620.0	6807779.0	191.7	435465.5	6807372.6	195.6	Off
263	435620.0	6807779.0	191.7	435472.0	6807375.5	195.6	Off
264	435620.0	6807779.0	191.7	435474.8	6807374.4	195.1	Off
265	435620.0	6807779.0	191.7	435474.7	6807369.2	193.5	Off
266	435620.0	6807779.0	191.7	435111.0	6807419.8	239.0	Off
267	435620.0	6807779.0	191.7	435090.6	6807396.8	240.6	Off
268	435620.0	6807779.0	191.7	435115.2	6807413.8	237.7	Off
269	435620.0	6807779.0	191.7	435112.1	6807418.3	239.0	Off
270	435620.0	6807779.0	191.7	435113.1	6807416.8	239.0	Off
271	435620.0	6807779.0	191.7	435550.7	6807818.3	185.0	Off
272	435620.0	6807779.0	191.7	435555.1	6807816.1	185.6	Off
273	435620.0	6807779.0	191.7	435559.5	6807813.7	185.8	Off
274	435620.0	6807779.0	191.7	435550.8	6807818.5	184.8	Off
275	435620.0	6807779.0	191.7	435555.5	6807816.7	185.6	Off
276	435620.0	6807779.0	191.7	435623.6	6807938.7	198.8	Off
277	435620.0	6807779.0	191.7	435623.0	6807938.7	199.0	Off
278	435620.0	6807779.0	191.7	435623.6	6807938.7	198.8	Off
279	435620.0	6807779.0	191.7	435624.1	6807933.8	198.0	Off
280	435620.0	6807779.0	191.7	435624.5	6807938.7	199.0	Off
281	435620.0	6807779.0	191.7	435723.2	6807920.1	198.6	Off
282	435620.0	6807779.0	191.7	435722.3	6807920.7	197.9	Off
283	435620.0	6807779.0	191.7	435721.8	6807921.1	198.4	Off
284	435620.0	6807779.0	191.7	435721.6	6807921.2	198.6	Off
285	435620.0	6807779.0	191.7	435722.5	6807920.6	198.3	Off
286	435620.0	6807779.0	191.7	435859.6	6807949.9	210.6	Off
287	435620.0	6807779.0	191.7	435862.6	6807954.2	211.8	Off
288	435620.0	6807779.0	191.7	435863.1	6807953.4	211.8	Off
289	435620.0	6807779.0	191.7	435859.9	6807949.4	210.9	Off
290	435620.0	6807779.0	191.7	435858.7	6807951.0	211.1	Off
291	435620.0	6807779.0	191.7	435692.2	6807725.3	190.7	Off

Measurement no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
292	435620.0	6807779.0	191.7	435688.0	6807728.1	190.7	Off
293	435620.0	6807779.0	191.7	435707.7	6807712.7	190.1	Off
294	435620.0	6807779.0	191.7	435692.0	6807725.1	190.5	Off
295	435620.0	6807779.0	191.7	435704.1	6807716.2	190.3	Off
296	435620.0	6807779.0	191.7	435572.4	6807377.0	195.3	Off
297	435620.0	6807779.0	191.7	435571.8	6807372.0	195.4	Off
298	435620.0	6807779.0	191.7	435572.0	6807377.0	195.3	Off
299	435620.0	6807779.0	191.7	435577.0	6807406.6	195.1	Off
300	435620.0	6807779.0	191.7	435575.7	6807401.7	194.4	Off
301	435620.0	6807779.0	191.7	435467.1	6807372.0	197.3	Off
302	435620.0	6807779.0	191.7	435466.3	6807372.3	196.5	Off
303	435620.0	6807779.0	191.7	435468.7	6807371.4	196.9	Off
304	435620.0	6807779.0	191.7	435466.3	6807372.3	197.7	Off
305	435620.0	6807779.0	191.7	435469.7	6807376.3	195.6	Off
306	435620.0	6807779.0	191.7	435107.1	6807417.0	241.2	Off
307	435620.0	6807779.0	191.7	435108.4	6807424.0	242.6	Off
308	435620.0	6807779.0	191.7	435111.7	6807418.8	239.0	Off
309	435620.0	6807779.0	191.7	435109.0	6807422.8	240.2	Off
310	435620.0	6807779.0	191.7	435106.4	6807418.0	241.2	Off
311	435620.0	6807779.0	191.7	435555.2	6807816.3	186.4	Off
312	435620.0	6807779.0	191.7	435555.2	6807816.4	186.4	Off
313	435620.0	6807779.0	191.7	435559.7	6807814.1	186.8	Off
314	435620.0	6807779.0	191.7	435555.1	6807816.2	186.2	Off
315	435620.0	6807779.0	191.7	435555.4	6807816.6	186.5	Off
316	435620.0	6807779.0	191.7	435625.6	6807933.7	198.0	Off
317	435620.0	6807779.0	191.7	435626.3	6807938.7	199.0	Off
318	435620.0	6807779.0	191.7	435626.5	6807933.6	198.7	Off
319	435620.0	6807779.0	191.7	435626.1	6807933.7	198.3	Off
320	435620.0	6807779.0	191.7	435626.7	6807938.6	199.0	Off
321	435620.0	6807779.0	191.7	435679.0	6807859.6	196.0	Off
322	435620.0	6807779.0	191.7	435676.2	6807855.4	195.3	Off
323	435620.0	6807779.0	191.7	435679.5	6807859.2	195.7	Off
324	435620.0	6807779.0	191.7	435679.5	6807859.2	195.7	Off
325	435620.0	6807779.0	191.7	435679.4	6807859.3	195.8	Off
326	435620.0	6807779.0	191.7	435865.8	6807949.6	211.5	Off
327	435620.0	6807779.0	191.7	435868.2	6807946.3	210.0	Off
328	435620.0	6807779.0	191.7	435863.3	6807944.7	210.0	Off
329	435620.0	6807779.0	191.7	435867.1	6807948.0	210.0	Off
330	435620.0	6807779.0	191.7	435865.0	6807950.8	211.8	Off
331	435620.0	6807779.0	191.7	435708.0	6807713.1	190.8	Off
332	435620.0	6807779.0	191.7	435707.5	6807712.5	190.3	Off
333	435620.0	6807779.0	191.7	435703.2	6807715.0	190.2	Off
334	435620.0	6807779.0	191.7	435708.1	6807713.2	190.7	Off
335	435620.0	6807779.0	191.7	435708.1	6807713.2	190.9	Off
336	435620.0	6807779.0	191.7	435576.0	6807376.6	194.9	Off
337	435620.0	6807779.0	191.7	435577.6	6807376.4	194.1	Off
338	435620.0	6807779.0	191.7	435577.4	6807371.4	194.6	Off
339	435620.0	6807779.0	191.7	435576.8	6807376.5	195.3	Off
340	435620.0	6807779.0	191.7	435575.2	6807376.7	194.5	Off
341	435620.0	6807779.0	191.7	435471.1	6807370.5	196.5	Off
342	435620.0	6807779.0	191.7	435472.7	6807369.9	196.0	Off
343	435620.0	6807779.0	191.7	435472.3	6807370.0	196.0	Off
344	435620.0	6807779.0	191.7	435472.3	6807370.0	196.0	Off

Measurement no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
345	435620.0	6807779.0	191.7	435470.7	6807370.6	196.5	Off
346	435620.0	6807779.0	191.7	435086.5	6807394.6	245.5	Off
347	435620.0	6807779.0	191.7	435111.0	6807411.5	241.8	Off
348	435620.0	6807779.0	191.7	435092.3	6807394.8	243.2	Off
349	435620.0	6807779.0	191.7	435115.2	6807414.5	242.6	Off
350	435620.0	6807779.0	191.7	435117.1	6807411.4	239.6	Off
351	435620.0	6807779.0	191.7	435555.2	6807816.2	186.4	Off
352	435620.0	6807779.0	191.7	435554.9	6807815.8	186.3	Off
353	435620.0	6807779.0	191.7	435555.0	6807815.9	186.2	Off
354	435620.0	6807779.0	191.7	435555.0	6807815.9	186.4	Off
355	435620.0	6807779.0	191.7	435555.1	6807816.2	186.5	Off
356	435620.0	6807779.0	191.7	435626.2	6807933.7	198.6	Off
357	435620.0	6807779.0	191.7	435626.0	6807943.7	199.2	Off
358	435620.0	6807779.0	191.7	435625.8	6807933.7	198.1	Off
359	435620.0	6807779.0	191.7	435625.6	6807938.7	198.3	Off
360	435620.0	6807779.0	191.7	435626.1	6807938.7	198.7	Off
361	435620.0	6807779.0	191.7	435679.0	6807859.6	195.6	Off
362	435620.0	6807779.0	191.7	435682.0	6807863.6	196.1	Off
363	435620.0	6807779.0	191.7	435680.1	6807858.8	195.4	Off
364	435620.0	6807779.0	191.7	435679.0	6807859.6	195.7	Off
365	435620.0	6807779.0	191.7	435676.4	6807855.3	195.6	Off
366	435620.0	6807779.0	191.7	435866.3	6807948.9	211.5	Off
367	435620.0	6807779.0	191.7	435867.7	6807947.0	210.9	Off
368	435620.0	6807779.0	191.7	435867.7	6807947.0	210.6	Off
369	435620.0	6807779.0	191.7	435866.9	6807948.2	210.6	Off
370	435620.0	6807779.0	191.7	435862.2	6807946.1	210.9	Off
371	435620.0	6807779.0	191.7	435706.1	6807710.7	190.2	Off
372	435620.0	6807779.0	191.7	435691.1	6807723.9	190.8	Off
373	435620.0	6807779.0	191.7	435702.9	6807714.7	190.7	Off
374	435620.0	6807779.0	191.7	435702.3	6807713.9	190.1	Off
375	435620.0	6807779.0	191.7	435706.3	6807710.9	190.3	Off
376	435620.0	6807779.0	191.7	435570.6	6807397.3	195.2	Off
377	435620.0	6807779.0	191.7	435574.6	6807401.9	194.7	Off
378	435620.0	6807779.0	191.7	435571.7	6807402.2	193.6	Off
379	435620.0	6807779.0	191.7	435575.8	6807411.8	194.3	Off
380	435620.0	6807779.0	191.7	435567.3	6807377.6	194.5	Off
381	435620.0	6807779.0	191.7	435465.3	6807367.3	196.9	Off
382	435620.0	6807779.0	191.7	435467.1	6807372.0	196.9	Off
383	435620.0	6807779.0	191.7	435461.3	6807368.8	196.5	Off
384	435620.0	6807779.0	191.7	435464.3	6807373.0	196.5	Off
385	435620.0	6807779.0	191.7	435465.9	6807372.4	196.9	Off
386	435620.0	6807779.0	191.7	435106.4	6807418.0	241.8	Off
387	435620.0	6807779.0	191.7	435112.2	6807418.4	241.4	Off
388	435620.0	6807779.0	191.7	435107.8	6807416.0	241.8	Off
389	435620.0	6807779.0	191.7	435113.6	6807416.4	240.8	Off
390	435620.0	6807779.0	191.7	435111.5	6807419.4	240.8	Off
391	435620.0	6807779.0	191.7	435555.2	6807816.3	186.4	Off
392	435620.0	6807779.0	191.7	435555.3	6807816.4	186.4	Off
393	435620.0	6807779.0	191.7	435555.0	6807816.1	186.4	Off
394	435620.0	6807779.0	191.7	435555.1	6807816.2	186.5	Off
395	435620.0	6807779.0	191.7	435550.5	6807818.0	185.9	Off
396	435620.0	6807779.0	191.7	435625.2	6807938.7	198.5	Off
397	435620.0	6807779.0	191.7	435624.9	6807938.7	198.8	Off

Measure ment no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
398	435620.0	6807779.0	191.7	435625.2	6807933.7	198.4	Off
399	435620.0	6807779.0	191.7	435625.2	6807938.7	198.8	Off
400	435620.0	6807779.0	191.7	435625.3	6807938.7	198.7	Off
401	435620.0	6807779.0	191.7	435727.2	6807923.3	198.6	Off
402	435620.0	6807779.0	191.7	435726.7	6807923.7	198.5	Off
403	435620.0	6807779.0	191.7	435723.6	6807919.8	198.4	Off
404	435620.0	6807779.0	191.7	435726.4	6807923.9	198.6	Off
405	435620.0	6807779.0	191.7	435723.7	6807919.7	198.4	Off
406	435620.0	6807779.0	191.7	435868.3	6807946.0	210.9	Off
407	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
408	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
409	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
410	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
411	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
412	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
413	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
414	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
415	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
416	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
417	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
418	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
419	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
420	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
421	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
422	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
423	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
424	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
425	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
426	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
427	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
428	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
429	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
430	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
431	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
432	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
433	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
434	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
435	435620.0	6807779.0	191.7	435620.0	6807779.0	191.7	Off
439	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
440	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
441	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
442	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
443	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
444	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
445	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
446	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
447	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
448	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
449	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
450	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
451	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
452	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off

Measure ment no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
453	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
454	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
455	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
456	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
457	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
458	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
459	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
460	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
461	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
462	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
463	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
464	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
465	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
466	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
467	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
468	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
469	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
470	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
471	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
472	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
473	435608.0	6807896.0	635.0	435608.0	6807896.0	635.0	Off
474	435691.0	6807866.0	191.7	435691.0	6807866.0	191.7	On
475	435659.0	6807826.0	191.7	435659.0	6807826.0	191.7	On
476	435631.0	6807918.0	558.9	435631.0	6807918.0	558.9	On
477	435639.0	6807967.0	513.5	435639.0	6807967.0	513.5	On
478	435599.0	6807973.0	491.5	435599.0	6807973.0	491.5	On
479	435594.0	6807970.0	486.7	435594.0	6807970.0	486.7	On
480	435591.0	6807954.0	483.7	435591.0	6807954.0	483.7	On
481	435589.0	6807924.0	482.0	435589.0	6807924.0	482.0	On
482	435641.0	6807981.0	482.0	435641.0	6807981.0	482.0	On
483	435568.0	6807851.0	565.9	435568.0	6807851.0	565.9	On
484	435667.0	6807960.0	451.4	435667.0	6807960.0	451.4	On
485	435617.0	6807919.0	595.5	435617.0	6807919.0	595.5	On
486	435619.0	6807917.0	594.2	435619.0	6807917.0	594.2	On
488	435595.0	6808023.0	595.2	435595.0	6808023.0	595.2	On
489	435605.0	6807987.0	599.8	435605.0	6807987.0	599.8	On
490	435635.0	6807966.0	477.5	435635.0	6807966.0	477.5	On
491	435640.0	6808021.0	514.6	435640.0	6808021.0	514.6	On
492	435626.0	6807916.0	557.4	435626.0	6807916.0	557.4	On
493	435608.0	6807877.0	561.9	435608.0	6807877.0	561.9	On
494	435590.0	6807959.0	606.5	435590.0	6807959.0	606.5	On
495	435606.0	6807910.0	624.8	435606.0	6807910.0	624.8	On
496	435678.0	6807936.0	558.0	435678.0	6807936.0	558.0	On
497	435672.0	6807930.0	598.4	435672.0	6807930.0	598.4	On
498	435547.0	6807865.0	668.8	435547.0	6807865.0	668.8	On
499	435568.0	6807873.0	637.0	435568.0	6807873.0	637.0	On
500	435596.0	6807929.0	604.1	435596.0	6807929.0	604.1	On
501	435577.0	6807916.0	614.6	435577.0	6807916.0	614.6	On
502	435614.0	6807745.0	191.7	435614.0	6807745.0	191.7	On
503	435590.0	6807853.0	406.8	435590.0	6807853.0	406.8	On
504	435596.0	6807920.0	580.3	435596.0	6807920.0	580.3	On
505	435610.0	6807928.0	565.2	435610.0	6807928.0	565.2	On

Measurement no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
506	435619.0	6807935.0	554.4	435619.0	6807935.0	554.4	On
507	435602.0	6807935.0	549.2	435602.0	6807935.0	549.2	On
508	435599.0	6807937.0	544.3	435599.0	6807937.0	544.3	On
509	435596.0	6807936.0	539.5	435596.0	6807936.0	539.5	On
510	435593.0	6807935.0	534.7	435593.0	6807935.0	534.7	On
511	435590.0	6807934.0	531.7	435590.0	6807934.0	531.7	On
512	435587.0	6807929.0	530.0	435587.0	6807929.0	530.0	On
513	435588.0	6807928.0	532.8	435588.0	6807928.0	532.8	On
514	435591.0	6807929.0	542.7	435591.0	6807929.0	542.7	On
515	435595.0	6807930.0	552.9	435595.0	6807930.0	552.9	On
516	435603.0	6807931.0	567.0	435603.0	6807931.0	567.0	On
517	435596.0	6807928.0	573.2	435596.0	6807928.0	573.2	On
518	435620.0	6807909.0	579.4	435620.0	6807909.0	579.4	On
519	435622.0	6807901.0	576.4	435622.0	6807901.0	576.4	On
520	435621.0	6807889.0	564.1	435621.0	6807889.0	564.1	On
521	435619.0	6807877.0	550.2	435619.0	6807877.0	550.2	On
522	435623.0	6807877.0	548.2	435623.0	6807877.0	548.2	On
523	435630.0	6807886.0	556.5	435630.0	6807886.0	556.5	On
524	435638.0	6807902.0	566.6	435638.0	6807902.0	566.6	On
525	435644.0	6807918.0	572.3	435644.0	6807918.0	572.3	On
526	435649.0	6807933.0	574.3	435649.0	6807933.0	574.3	On
527	435651.0	6807962.0	568.0	435651.0	6807962.0	568.0	On
528	435649.0	6807966.0	558.7	435649.0	6807966.0	558.7	On
529	435646.0	6807967.0	547.5	435646.0	6807967.0	547.5	On
530	435644.0	6807964.0	538.4	435644.0	6807964.0	538.4	On
531	435641.0	6807958.0	532.7	435641.0	6807958.0	532.7	On
532	435637.0	6807950.0	530.5	435637.0	6807950.0	530.5	On
533	435633.0	6807942.0	536.3	435633.0	6807942.0	536.3	On
534	435629.0	6807934.0	548.6	435629.0	6807934.0	548.6	On
535	435624.0	6807929.0	565.1	435624.0	6807929.0	565.1	On
536	435619.0	6807926.0	582.1	435619.0	6807926.0	582.1	On
537	435609.0	6807926.0	614.2	435609.0	6807926.0	614.2	On
538	435607.0	6807929.0	627.6	435607.0	6807929.0	627.6	On
539	435605.0	6807932.0	635.9	435605.0	6807932.0	635.9	On
540	435605.0	6807934.0	639.1	435605.0	6807934.0	639.1	On
541	435606.0	6807936.0	634.5	435606.0	6807936.0	634.5	On
542	435608.0	6807932.0	618.8	435608.0	6807932.0	618.8	On
543	435609.0	6807925.0	590.7	435609.0	6807925.0	590.7	On
544	435608.0	6807911.0	551.5	435608.0	6807911.0	551.5	On
545	435606.0	6807902.0	533.9	435606.0	6807902.0	533.9	On
546	435604.0	6807897.0	523.3	435604.0	6807897.0	523.3	On
547	435607.0	6807887.0	652.6	435607.0	6807887.0	652.6	On
548	435606.0	6807887.0	653.4	435606.0	6807887.0	653.4	On
549	435604.0	6807890.0	654.1	435604.0	6807890.0	654.1	On
550	435603.0	6807896.0	657.0	435603.0	6807896.0	657.0	On
551	435604.0	6807901.0	657.4	435604.0	6807901.0	657.4	On
552	435606.0	6807909.0	652.5	435606.0	6807909.0	652.5	On
553	435608.0	6807915.0	643.8	435608.0	6807915.0	643.8	On
554	435609.0	6807928.0	622.4	435609.0	6807928.0	622.4	On
555	435611.0	6807933.0	605.2	435611.0	6807933.0	605.2	On
556	435610.0	6807936.0	582.6	435610.0	6807936.0	582.6	On
557	435607.0	6807940.0	547.6	435607.0	6807940.0	547.6	On
558	435605.0	6807941.0	542.6	435605.0	6807941.0	542.6	On

Measurement no	Own pos East	Own pos North	Own pos Altitude	Target East	Target North	Target Altitude	GPS On/Off
559	435604.0	6807940.0	545.3	435604.0	6807940.0	545.3	On
560	435603.0	6807940.0	553.6	435603.0	6807940.0	553.6	On
561	435603.0	6807941.0	572.4	435603.0	6807941.0	572.4	On
562	435566.0	6807953.0	581.0	435566.0	6807953.0	581.0	On
563	435612.0	6807944.0	631.6	435612.0	6807944.0	631.6	On
564	435618.0	6807944.0	654.9	435618.0	6807944.0	654.9	On
565	435626.0	6807946.0	677.1	435626.0	6807946.0	677.1	On
566	435632.0	6807948.0	692.5	435632.0	6807948.0	692.5	On
567	435609.0	6807935.0	591.2	435609.0	6807935.0	591.2	On
568	435606.0	6807931.0	562.3	435606.0	6807931.0	562.3	On
569	435607.0	6807932.0	546.1	435607.0	6807932.0	546.1	On
570	435610.0	6807936.0	538.5	435610.0	6807936.0	538.5	On
571	435614.0	6807942.0	539.8	435614.0	6807942.0	539.8	On
572	435623.0	6807954.0	551.0	435623.0	6807954.0	551.0	On
573	435631.0	6807962.0	557.8	435631.0	6807962.0	557.8	On
574	435641.0	6807971.0	564.5	435641.0	6807971.0	564.5	On
575	435648.0	6807976.0	565.9	435648.0	6807976.0	565.9	On
576	435656.0	6807979.0	563.6	435656.0	6807979.0	563.6	On
577	435712.0	6807952.0	571.8	435712.0	6807952.0	571.8	On
578	435662.0	6807930.0	559.2	435662.0	6807930.0	559.2	On
579	435658.0	6807915.0	561.3	435658.0	6807915.0	561.3	On
580	435650.0	6807904.0	579.3	435650.0	6807904.0	579.3	On
581	435642.0	6807898.0	598.3	435642.0	6807898.0	598.3	On
582	435636.0	6807895.0	614.7	435636.0	6807895.0	614.7	On
583	435631.0	6807893.0	625.9	435631.0	6807893.0	625.9	On
584	435627.0	6807894.0	634.8	435627.0	6807894.0	634.8	On
585	435623.0	6807895.0	639.5	435623.0	6807895.0	639.5	On
586	435620.0	6807915.0	660.3	435620.0	6807915.0	660.3	On
587	435607.0	6807908.0	659.1	435607.0	6807908.0	659.1	On
588	435615.0	6807909.0	628.2	435615.0	6807909.0	628.2	On
589	435615.0	6807909.0	614.1	435615.0	6807909.0	614.1	On

C MEASUREMENTS WITH THE NORTHFINDER AND THE GONIOMETER

The table shows the orientation of the northfinder during the trials. Northfinder azimuth is the angle between the zero line of the northfinder and grid north. Northfinder elevation and roll are the angles about the axis perpendicular and parallel respectively, with the zero line of the northfinder. All angels are measured in mils.

North-seek no.	Northfinder azimuth	Northfinder elevation	Northfinder roll
1	3731.1	31.7	35.4
2	3730.8	31.7	35.3
3	3734.9	31.7	35.3
4	3734.4	31.8	35.3
5	3728.0	31.8	35.3
6	3730.4	31.8	35.3
7	3731.9	31.8	35.3
8	3731.5	31.8	35.3
9	3732.9	31.8	35.3
10	3743.7	31.8	35.3
11	3753.5	31.8	35.3
12	3736.4	-135.6	57.4
13	3740.4	-135.5	57.4
14	3732.0	-135.5	57.4
15	3737.4	-135.6	57.4
16	3732.5	-135.5	57.4
17	3739.4	-135.6	57.4
18	3738.1	-135.6	57.4
19	3744.5	-135.6	57.4
20	3726.8	-135.6	57.4
21	3736.5	-135.6	57.4

Table C.1: The orientation of the northfinder for every measurement

North-seek no.	AP1	AP2	AP3	AP4	AP5	AP6	AP7	AP8	AP9	AP1 El	AP2 El	AP3 El	AP4 El	AP5 El	AP6 El	AP7 El	AP8 El	AP9 El
1	35	659	999	2311	3393	3636	4230	5324	0	47	39	65	-13	8	12	83	-73	0
2	36	659	999	2311	3394	3636	4231	5324	0	43	39	64	-15	6	11	81	-76	0
3	0	0	0	0	0	3641	0	0	4066	0	0	0	0	0	10	0	0	90
4	0	0	0	0	0	3640	0	0	4066	0	0	0	0	0	11	0	0	90
5	0	0	0	0	0	3634	0	0	4060	0	0	0	0	0	10	0	0	90
6	0	0	0	0	0	3636	0	0	4062	0	0	0	0	0	11	0	0	90
7	0	0	0	0	0	3638	0	0	4063	0	0	0	0	0	11	0	0	88
8	0	0	0	0	0	3637	0	0	4063	0	0	0	0	0	10	0	0	90
9	0	0	0	0	0	3639	0	0	4064	0	0	0	0	0	10	0	0	90
10	0	0	0	0	0	3649	0	0	4075	0	0	0	0	0	9	0	0	89
11	0	0	0	0	0	3659	0	0	4085	0	0	0	0	0	9	0	0	89
12	39	660	999	2307	3392	3636	4232	5329	4063	45	39	64	-16	4	11	81	-75	89
13	0	0	0	0	0	3640	0	0	4067	0	0	0	0	0	10	0	0	90
14	0	0	0	0	0	3631	0	0	4059	0	0	0	0	0	11	0	0	90
15	0	0	0	0	0	3637	0	0	4064	0	0	0	0	0	11	0	0	91
16	0	0	0	0	0	3632	0	0	4059	0	0	0	0	0	9	0	0	90
17	0	0	0	0	0	3639	0	0	4066	0	0	0	0	0	11	0	0	89
18	0	0	0	0	0	3637	0	0	4065	0	0	0	0	0	10	0	0	90
19	0	0	0	0	0	3644	0	0	4071	0	0	0	0	0	10	0	0	89
20	0	0	0	0	0	3626	0	0	4053	0	0	0	0	0	10	0	0	90
21	0	0	0	0	0	3636	0	0	4063	0	0	0	0	0	10	0	0	90

Table C.2: *The table shows the results from aiming at the targets (AP) 1 to 9. There is one raw for each north-seek. Column 2 to 10 contains azimuth measurements and column 11 to 19 contains elevation measurements. Azimuth and elevation to the target is refered to grid north and the horizontal plane, respectively. All angles are measured in mils.*

D POSITION, RANGE AND AZIMUTH REFERENCES

Position and range:

Target no	East	North	Altitude	Range (m)
O 62	432507	6818061	675	-
1	432189	6818557	626	591
2	431968	6819334	640	1383
3	431851	6819544	641	1622
4	433596	6819767	634	2024
5	432735	6818592	620	581

Figure A.1: Position and range references (in UTM WGS84).
References are calculated from the given positions, and they are valid for measurement no 132 to 211. O 62 is the position of the instrument.

Azimuth:

Target no	Azimuth (mils)
1	41.7
2	664.4
3	1004.7
4	2316.2
5	3401.1
6	3643.9
7	4238.2
8	5333.3
9	4070.9

Figure A.2: Azimuth references.
The references are refered to grid north, and they were established with an inertial navigation system. The references are valid for measurement no 236 to 589.

References

(1) Grøder T (1996): Brukerprøver med håndholdt ildledningsinstrument (testversjon) og beregning av forventet totalnøyaktighet, FFI/RAPPORT-96/04001, Forsvarets forskningsinstitutt (Offentlig tilgjengelig).

(2) Leica Geosystems AG (1997): SG12S Digital Goniometer, Operator Manual - Draft.

FORDELINGSLISTE

FFIS **Dato:** 1 november 1999

RAPPORT TYPE (KRYSS AV)	RAPPORT NR	REFERANSE	RAPPORTENS DATO
X RAPP ☐ NOTAT ☐ RR	99/05414	FFIS/697/134	1 november 1999

RAPPORTENS BESKYTTELSESGRAD	ANTALL EKS UTSTEDT	ANTALL SIDER
UGRADERT	50	74

RAPPORTENS TITTEL	FORFATTER(E)
FORWARD OBSERVER INSTRUMENT FUNCTIONAL MODEL - USER TRIALS AT ÄLVDALEN, SWEDEN, 12 - 17 NOVEMBER 1998	GRØDER Torbjørn, KANDOLA Ørnulf

FORDELING GODKJENT AV FORSKNINGSSJEF:	FORDELING GODKJENT AV ADM DIREKTØR:
Stian Løvold	Paul Narum

EKSTERN FORDELING

ANTALL	EKS NR	TIL
20		Simrad Optronics ASA

INTERN FORDELING

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1		FFIS
1		FFISYS
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