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The RA Svy GPS Experience — 1987/1988

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Abstract

Since early 1987, the Royal Australian Survey Corps (RA Svy) has utilised the versatile Texas Instruments TI 4100 GPS receivers in various configurations and on diverse tasks. This paper reports on existing RA Svy GPS applications, project results, data processing capabilities, proposed applications and training for managers and operators. Applications to date include: small ship P code navigation, establishment of precision three-dimensional test ranges for RA Svy GPS, TRANSIT Doppler and inertial survey equipments, densification of existing horizontal and vertical networks for 1:50 000 scale topographic mapping, observations for orbit determination for projects in Australia and the Caribbean area of Central America, observations for University of New South Wales ionospheric refraction research, vehicle-mounted precise kinematic relative positioning and precise point positioning. Results include networks and baselines observed using NAVIGATOR and GESAR operating systems and processed by programmes GEOMARK™ and PHASER respectively, kinematic relative positioning and precise point positions processed by programme LAST GASP. RA Svy proposes to trial a TI 4100-based aircraft-mounted precise kinematic relative positioning system integrated with a WILD RC10 camera between December 1988 and April 1989. Other proposed applications include vertification of position of topographic data base and map information.

1.0 Introduction

The Royal Australian Survey Corps (RA Svy) involvement in the Global Positioning System (GPS) began in March 1981 with the commencement of GPS observations at the GPS/TRANET Station Smithfield, South Australia in conjunction with the United States Defense Mapping Agency (DMA). This ongoing commitment provides data for the computation of precise ephemerides which are available to approved users (through RA Svy) in Australia.

Since then, RA Svy has embarked on a programme of utilising GPS to provide timely and accurate survey data to the Australian Defence Force.

2.0 Equipment

2.1 Initial Equipment Tests

In February 1987, nine TI 4100 (NAV) RAM receivers were tested with antennas sited in a 3 x 3 matrix with each antenna about 30 metres from the nearest antenna (See Figure 1). Fifteen minutes of simultaneous observation data were processed by GEOMARK™ using double differencing. Miscloses of delta cartesian co-ordinates (WGS84) of the nine baseline polygon were: dX + 0.002m, dY − 0.002m, dZ + 0.003m.

2.2. Equipment Documentation

In support of RA Svy GPS training, the School of Military Survey has prepared a Standing Operating Procedure (SOP) for the TI 4100 and post-processing micro-computer. The SOP documents all aspects of TI 4100 employment by RA Svy including:

- equipment operation with NAVIGATOR and GESAR operating systems,
- project planning,

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- mission planning.
- data processing using GEOMARK™.
- report preparation.
- dynamic navigation.
- enhanced mode operations.

In addition to the TI 4100 SOP. Directorate of Survey — Army (DSVY—A) has issued a Technical Instruction detailing standards and specifications for the planning, execution and post-processing of static horizontal and vertical relative control surveys. These standards are based upon those in IGACSM 1988.

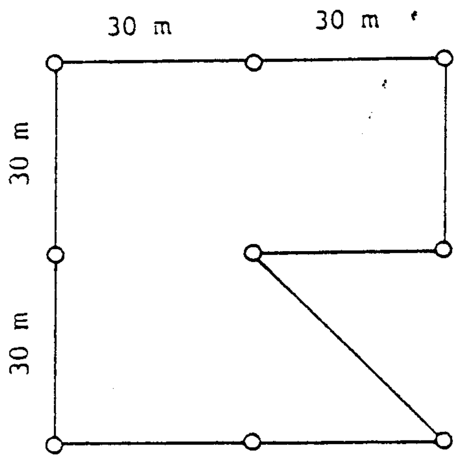


Figure 1. Initial Equipment Test Baseline Configuration

2.3 Evaluation of TI 4100 PLUS

Since release of the TI 4100, Texas Instruments has released several software upgrades including the latest TI NAVIGATOR III which features WGS-84 orbital parameters. In conjunction with the NAV III release, TI upgraded the TI 4100 firmware with a series of replacement chips designed to improve tracking performance.

The upgraded receiver (TI 4100 PLUS) claimed improved:

- tracking loops.
- recovery from loss of lock.
- dynamic tracking.
- search stability, and
- C/A code performance.

In a static role comparison of the upgraded versus standard receiver, no appreciable performance improvement could be established. However, in the dynamic role the performance improvement was clearly evident. In a vehicle-mounted navigation trial undertaken with two receivers mounted in a vehicle, the NAV PLUS receiver was able to maintain 'navigation' through medium/dense timber — while the standard receiver lost its navigation solution. The vehicle had to be stopped in an open clearing for about 4 minutes in order to regain 'lock' on the full constellation.

3.0 Training

3.1 Non-RA Svy Training

In order to manage and develop the RA Svy GPS resources. the following training has been undertaken by RA Svy officers:

- post-graduate degrees in geodetic science:
- on the job training with the United States Defense Mapping Agency (DMA).

The six-month training for the officer posted to DMA included field training and equipment repair at the field office at Herndon, Virginia and post-processing of GPS data at DMA Hydrographic Topographic Centre (HTC) at Brookmont, Maryland. The officer who undertook this training was then responsible for the migration of the DMA precise relative and point positioning software in Section 5 to RA Svy computing facilities. Whilst in the United States. this officer was able to visit and discuss GPS with the following institutions:

- US Space Command GPS Master Control Station at Falcon Air Force Station. Colorado.
- US Air Force GPS Joint Program Office. Los Angeles.
- Magnavox Advanced Products. Los Angeles,
- Texas Instruments. Plano. Texas.
- Applied Research Laboratory. University of Texas. Austin. Texas.
- Texas Highways Department. Austin, Texas,
- National Geodetic Survey. Rockville. Maryland,
- University of Colorado. Boulder, Colorado.

3.2 RA Svy Training

Initial training for ten personnel in the use of the TI 4100. and SATPLAN™ and GEOMARK™ software. was provided by Texas Instruments Incorporated in February 1987. The School of Military Survey subsequently conducted the first GPS Manager and Operator course in a twenty training day period in February 1988.

This course covered all aspects of proposed RA Svy GPS employment and included formal instruction in:

- elementary GPS theory.
- receiver operation and maintenance. and
- TI Portable Professional Computer (TIPPC) operation using SATPLAN™ and GEOMARK™.

Operator training included use of both TI Navigator and GESAR operating systems for the TI 4100. and involved vehicle navigation and use of towers.

The fieldwork phase of the course comprised three exercises each involving:

- operation planning.
- field deployment. and
- post-processing and report generation.

The final exercise involved the upgrading of an equipment test range (see Section 4.1) to 1st Order standard. The task involved the measurement of 57 baselines to a total of 15 stations over distances up to 122 km.

4.0 Geodetic Survey Projects

4.1 Lake Hume Advanced Survey System Test Range

The test range situated west of Albury. NSW and within the RA Svy Lake Hume Photogrammetric Test Range was established by relative TRANSIT Doppler in late 1986 and also contains earlier conventional 3rd Order surveys. The test range was designed primarily to test the Ferranti Inertial Land Surveyor Mark 3 (FILS 3) equipment, and is also used to test GPS and TRANSIT Doppler equipment. In February 1987, the test range was upgraded and integrated into the surrounding 1st Order network by the School of Military Survey pilot GPS Manager/Operator course using RA Svy TI 4100 (NAV) receivers.

The internal network and connection to the existing survey was designed in accordance with IGACSM 1988 Recommended Practices for 1st Order GPS Surveys. The network stations and GPS baselines are shown in Figure 2. The network of 57 baselines was observed in five sessions over three days using up to six TI 4100's simultaneously, and observation periods of 60 minutes. Observation procedures were in accordance with IGACSM 1988 Recommended Practices for 1st Order GPS Surveys.

Observed data was reduced as single baselines using Texas Instruments GEOMARK™ software on TI PPC's. Baselines up to 30 km in length were processed by double differencing and baselines over 30 km by triple differencing with tropospheric refraction corrections. Polygon miscloses of delta cartesian co-ordinates (WGS84) for each session are summarised in Table 1.

Session	Stations	Perimeter Distance km	Misclose dX ppm	Misclose dY ppm	Misclose dZ ppm	Misclose Vector ppm	TD-Triple Diff DD-Double Diff
1	Talgarno, E527, Boomanoomana, H195, E520, Peddles, Talgarno	299.7	−1.7	−4.0	−0.9	4.5	4 x TD 2 x DD
2	Talgarno, E526 RM2, Boomanoomana, H195, E520, Peddles, Talgarno	303.7	−3.2	−0.3	+0.7	3.3	4 x TD 2 x DD
3	E520, E522, H176, E521, H195, E520	99.1	−3.4	−7.2	−1.7	8.2	2 x TD 3 x DD
4	E527, E522, E526, E527, E525	91.6	+0.9	+1.2	+0.2	1.5	1 x TD 3 x DD
5	E527, E523, H155, E522, E525, E524, E527	81.3	−1.1	−6.2	+0.04	6.3	1 x TD 5 x DD

Table 1 — Lake Hume Polygon Miscloses

The geodesic distances and azimuths derived from the geodetic co-ordinates of the GEOMARK™ solutions were input as observations into the two dimensional geodetic adjustment program GANET. There was no differentiation between trivial and non-trivial baselines and all baselines were included. Observation standard errors for both distances and directions were the equivalent of 2 ppm and 4 ppm for double difference and triple difference solutions respectively. The network was adjusted initially as a minimum constraint solution, with only one station fixed and the scale and orientation provided from the observations themselves. Analysis of this adjustment confirmed that the intended precision of the survey had been achieved. The network was then adjusted as a constrained solution with the three 1st Order Stations (Talgarno, Peddles, Boomanoomana) held fixed. A summary of the minimum

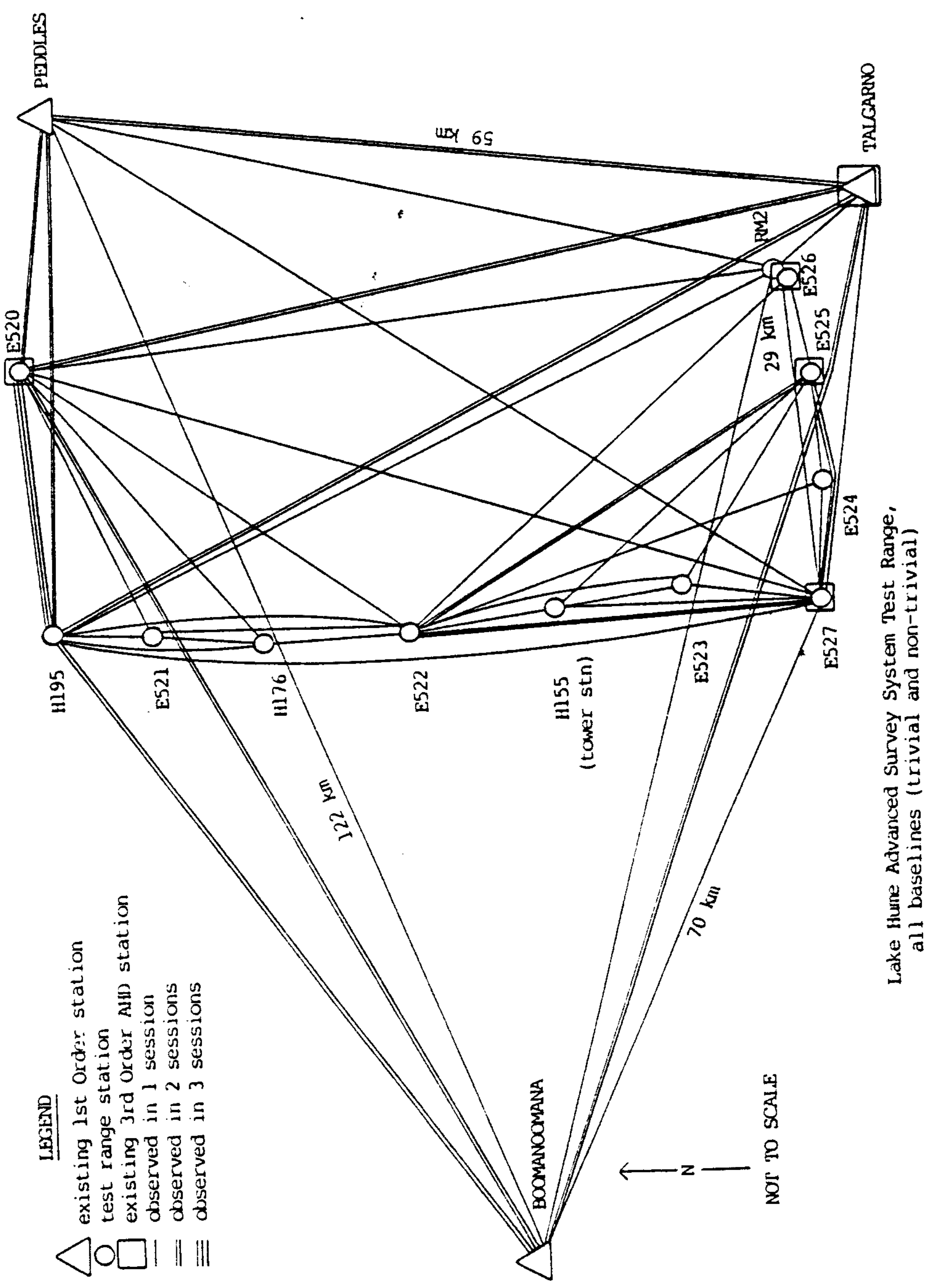

PEDDLES
TALGARNO
59 km
RM2
E526
E525
29 km
E520
E524
E527
H195
E521
H176
E522
H155
(tower stn)
E523
122 km
70 km
BOOMANOOMANA
N
NOT TO SCALE
LEGEND
existing 1st Order station
test range station
existing 3rd Order AHD station
observed in 1 session
observed in 2 sessions
observed in 3 sessions
Lake Hume Advanced Survey System Test Range,
all baselines (trivial and non-trivial)

Figure 2

constraint and constrained solutions is shown in Table 2. A comparison of the geodesic distances and azimuths as output by GEOMARK™ for the baselines between the three fixed 1st Order Stations, and the fixed AGD84 values is shown in Table 3.

	Minimum Constraint Adjustment	Integrated Adjustment
Degrees of Freedom	77	81
Degrees of Freedom/Station	5.5	6.8
A posteriori Variance Factor	1.02	1.02
Adjusted Relative Error Ellipses 95% confidence region:		
• Maximum	5.1 ppm	4.7 ppm
• Mean	3.2 ppm	2.7 ppm
• Standard Deviation	1.0 ppm	1.2 ppm
Distances:		
• Maximum residual (sign ignored)	7.7 ppm	8.2 ppm
• Mean residual (sign ignored)	2.2 ppm	2.2 ppm
• Standard deviation of residuals (sign ignored)	2.0 ppm	2.0 ppm
Azimuths:		
• Maximum residual (sign ignored)	2."08/10.1 ppm	2."02/9.8 ppm
• Mean residual (sign ignored)	0."47/2.3 ppm	0."47/2.3 ppm
• Standard deviation of residuals (sign ignored)	0."47/2.3 ppm	0."50/2.4 ppm

Table 2 — Lake Hume Horizontal Adjustments Summary

Baseline	Reduction Type (TD-Triple Difference)	Distance Difference Terrestrial-Observed	Azimuth Difference Terrestrial-Observed
TALGARNO — PEDDLES (58.8 km)	TD	+ 0.016m/+ 0.3 ppm	+ 0."409/+2 ppm
TALGARNO — BOOMANOOMANA (110.3 km)	TD	+ 0.234m/+ 2.1 ppm	− 0."049/− 0.2 ppm
PEDDLES — BOOMANOOMANA (122.2 km)	TD	− 0.367m/−3.0 ppm	− 0."745/− 3.6 ppm

Table 3 — Lake Hume, Terrestrial-Observed

The network comprised five stations with 3rd Order AHD heights. The GEOMARK™ delta ellipsoidal (ANS) heights were used as observations in a least squares minimum constraint height adjustment. Observation *a priori* standard errors were 2 ppm and 5 ppm for double and triple differencing respectively. This adjustment is summarised in Table 4.

	Value	Baseline Length	ppm
Maximum residual (sign ignored)	0.422m	59.4 km	7.1
Mean residual (sign ignored)	0.074m	42.7 km	1.7
Standard deviation of residuals (sign ignored)	0.092m	42.7 km	2.2

Table 4 — Lake Hume, Ellipsoid Minimum Constraint Height Adjustment Summary

The ellipsoid height differences were then transformed to geoid height differences by applying the geoid undulation differences as determined from NMC 1986 Annex E. The geoid height differences were then integrated into the AHD by a least squares adjustment constrained at the five AHD stations. This adjustment is summarised in Table 5. The estimated resolution and accuracy of geoid undulation differences from NMC 1986 Annex E were estimated as ± 0.25m. The height network will be readjusted using more precise geoid undulation differences.

	Value	Baseline Length	ppm
Maximum residual (sign ignored)	0.245m	16.2 km	15
Mean residual (sign ignored)	0.152m	42.7 km	3.6
Standard deviation of residuals (sign ignored)	0.15m	42.7 km	3.6

Table 5 — Lake Hume, AHD Constrained Height Adjustment Summary

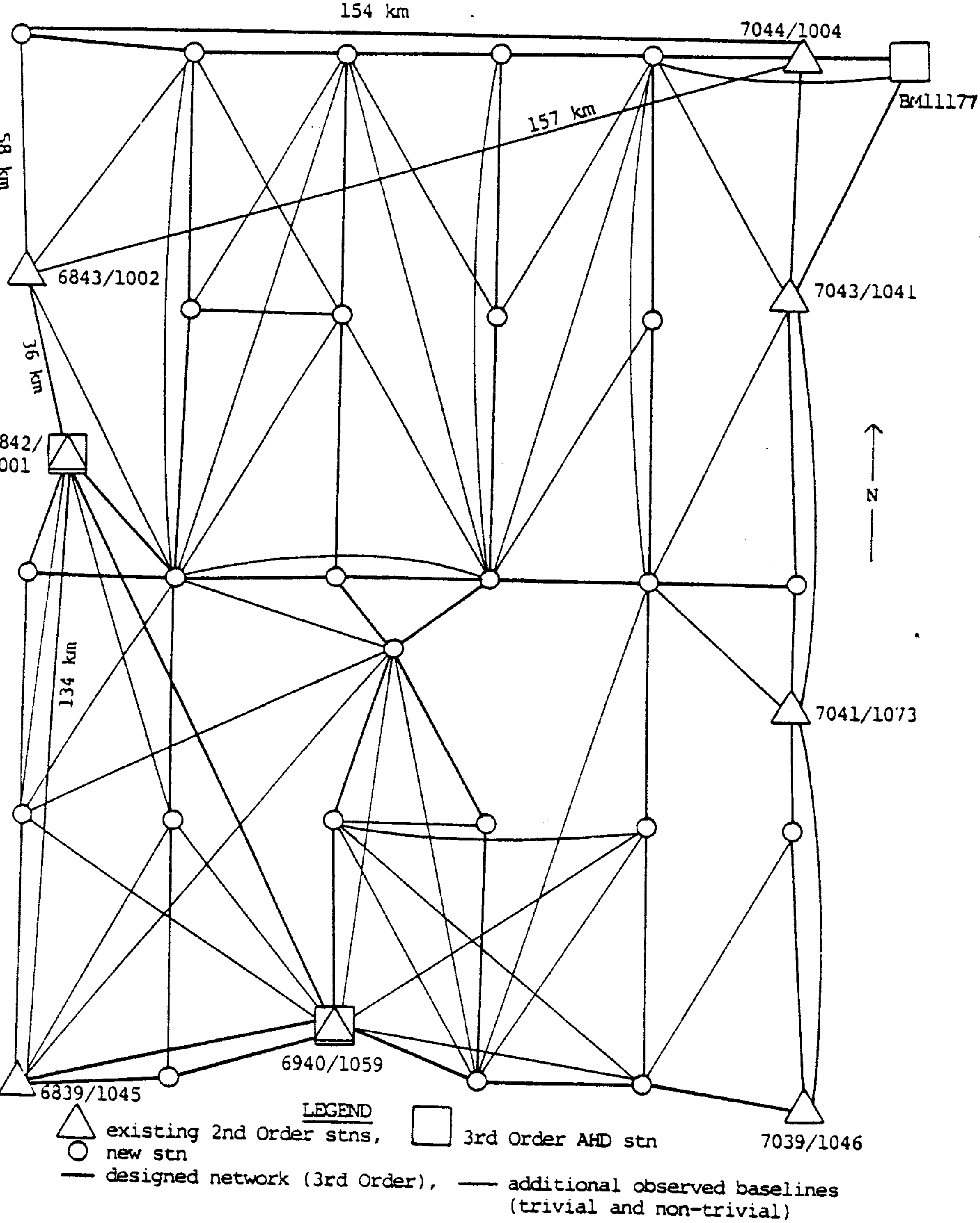
4.2 Cooper Basin SA

In April 1988 five TI 4100 (NAV) receivers were employed in the Cooper Basin of South Australia to provide horizontal and vertical control for 1:50 000 scale mapping and horizontal and vertical control for network densification by a Ferranti Inertial Land Surveyor Mark 3 (FILS 3).

The internal network and connection to the existing 2nd Order horizontal survey and 3rd Order level network was designed in accordance with the IGACSM 1988 Recommended Practices for 3rd Order GPS Surveys. The designed minimum baselines (52) for observation are shown in Figure 3. If only two receivers were employed, only the designed minimum baselines would have been observed. However, simply by default of using more than two receivers simultaneously, an additional 42 baselines were observed (see Figure 3).

Deploying three to five TI 4100s (an average of 3.7) the network was observed as 20 sessions over 21 days. Observation periods were 30 minutes and procedures were in accordance with the IGACSM 1988 Recommended Practices for 3rd Order GPS Surveys.

Observed data was reduced using GEOMARK™ in a similar manner to that of the Lake Hume project. Polygon miscloses of delta cartesian co-ordinates (WGS84) are summarised in Table 6.



Cooper Basin Network

Figure 3

	Perimeter Distance km	Misclose		
		dX ppm	dY ppm	dZ ppm
Max of 20 sessions	406.0	5.2	2.7	2.1
Mean of 20 sessions	206.1	1.4	0.9	0.5
Standard Deviation	69.1	1.5	0.8	0.5

Table 6 — Cooper Basin, Polygon Misclose Summary

The GEOMARK™-derived geodesic distances and azimuths were treated in a similar adjustment process to that of the Lake Hume project. The minimum constraint and constrained adjustments are summarised in Table 7. A comparison of the geodesic distances and azimuths as output by GEOMARK™ and the fixed values for the directly observed baselines between the eight fixed 2nd Order stations is shown in Table 8. The table shows that the relativity between the existing 2nd Order Stations is well within accepted 2nd Order Standards, and there is no significant difference between the AGD84 scale and orientation as derived by the GEOMARK™ transformation and the terrestrial AGD84 as defined by the co-ordinates of the 2nd Order Stations.

	Minimum Constraint Adjustment	Integrated Adjustment
Degrees of Freedom	266	280
Degrees of Freedom/Station	8.1	10.8
A posteriori Variance Factor	2.09	2.60
Adjusted Relative Error Ellipses 95% confidence region:		
• Maximum	10.0 ppm	8.6 ppm
• Mean	4.3 ppm	3.8 ppm
• Standard Deviation	1.5 ppm	1.6 ppm
Distances:		
• Maximum residual	25.8 ppm	20.4 ppm
• Mean residual (sign ignored)	3.2 ppm	3.6 ppm
• Standard deviation of residuals (sign ignored)	4.1 ppm	3.7 ppm
Azimuths:		
• Maximum residual	4."55/22.1 ppm	4."23/20.5 ppm
• Mean residual (sign ignored)	0."76/ 3.7 ppm	1."08/ 5.2 ppm
• Standard deviation of residuals (sign ignored)	0."75/ 3.7 ppm	0."90/ 4.4 ppm

Table 7 — Cooper Basin, Horizontal Adjustments Summary

Baseline	Reduction Type (TD-Triple Difference)	Distance Residual Terrestrial-Observed	Azimuth Residual Terrestrial-Observed
7044/1004-6843/1002 (157.2 km)	TD	+ 1.668m + 10.6 ppm	− 1."82 −8.8 ppm
7043/1041-7044/1004 (57.0 km)	TD	− 0.33m − 5.8 ppm	+ 0."49 + 2.4 ppm
6842/1001-6843/1002 (36.1 km)	TD	+ 0.020m + 0.6 ppm	− 2."46 − 11.9 ppm
7043/1041-7041/1073 (91.5 km)	TD	+ 0.201m + 2.2 ppm	− 2."24 − 10.7 ppm
6842/1001-6839/1045 (134.4 km)	TD	− 0.275m − 2.0 ppm	+ 0."54 + 2.6 ppm
6940/1059-6842/1001 (134.6 km)	TD	− 0.015m − 0.1 ppm	− 0."12 − 0.6 ppm
7041/1073-7034/1046 (80.7 km)	TD	+ 0.564m + 7.0 ppm	+ 1."95 + 9.5 ppm
6940/1059-6839/1045 (60.4 km)	TD TD	− 0.172m − 2.8 ppm + 0.197m + 2.4 ppm	+ 0."89 + 4.3 ppm + 0."79 + 3.8 ppm

Table 8 — Cooper Basin, Terrestrial — Observed Values

The GPS relative heights were related to the AHD by observations to three stations (6842/1001, 6940/1059, BM 11177) with 3rd Order AHD heights. The height adjustment was conducted in a similar manner to that of the Lake Hume project. The adjustment is summarised in Table 9. The GEOMARK™ and NMC 1986 Annex E - derived height differences and known 3rd Order AHD height differences for the line directly observed between benchmarks are in Table 10.

	Value	Baseline length	ppm
Maximum residual (sign ignored)	0.692m	30.2 km	22.9
Mean residual (sign ignored)	0.155m	53.4 km	2.9
Standard deviation of residuals (sign ignored)	0.155m	53.4 km	2.9

Table 9 — Cooper Basin, AHD Constrained Height Adjustment Summary

Baseline	Reduction Type (TD-Triple Diff)	Height Difference AHD — GPS Derived
6940/1059-6842/1001 (134.6 km)	TD	−0.210m/−1.6 ppm

Table 10 — Cooper Basin, AHD Heights — GPS Derived

4.3 Other Projects

Other geodetic projects have been the establishment of a high order test range in Sydney for FILS3, GPS and TRANSIT Doppler equipment, and a 1st Order test range in the Albury NSW area for a Total Camera Station mentioned in Section 6.0.

The Sydney observations included tests with TI 4100 antennas mounted on pneumatic towers up to 21m high (see Figure 4). A comparison of the tower tests in Table 11 shows that for observation periods of about 45 minutes, the use of towers up to 21m high should produce decimetre relative accuracies. Note that H155 in the Lake Hume project is a tower station.

Tower/Antenna Heights		Obs. Period (min.)	Monument to Monument Vector Component (WGS84)		
Stn. 1	Stn. 2		dX(m)	dY(m)	dZ(m)
10.69m	21.52m	50	+115.18	+40.45	−111.90
4.26m	4.44m	15	+114.92	+40.45	−111.74
1.867m	1.547m	45	+115.17	+40.57	−111.95

Table 11 — Tower Tests

The results of the Total Camera Station test range will not be reported in this paper, however the observation experience and results are similar to those of the Lake Hume project.

While this paper is being prepared, RA Svy and the South Australian Lands Department are conducting a joint project covering half of South Australia to primarily determine precise geoid undulation differences.

In June 1987, RA Svy observed dual frequency TI 4100 data for Prof F. Brunner's ionospheric refraction research at the University of New South Wales.

5.0 Data Processing

5.1 Observation Schedules

SATPLAN™ is used on field portable microcomputers in conjunction with criteria in IGACSM 1988 to determine satellite observation schedules.

5.2 Relative Positioning

GEOMARK™ is used on field portable microcomputers to field validate TI 4100 (NAV) data and to compute provisional co-ordinates. The capabilities of GEOMARK™ on lines up to 42 km are reported by Applegate *et al* 1986. Results on lines up to 157 km are reported in Section 4 of this paper.

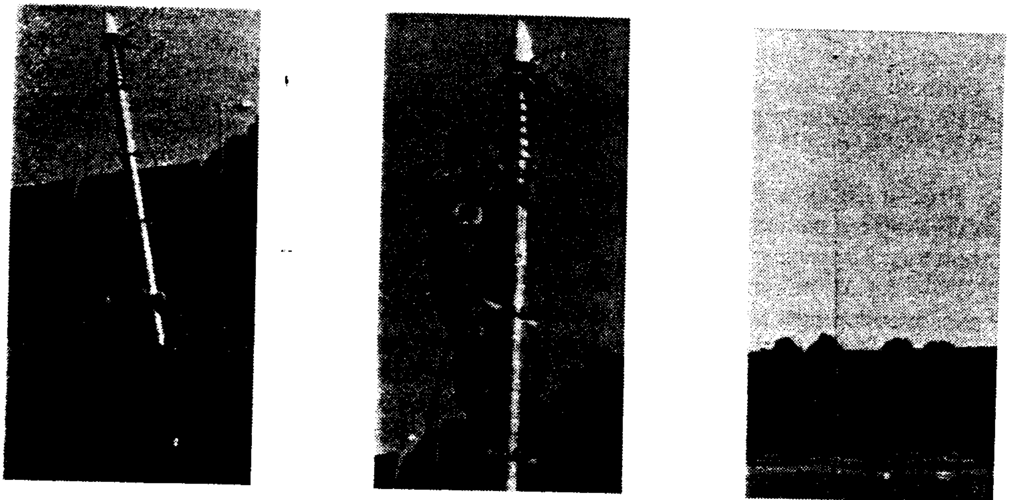
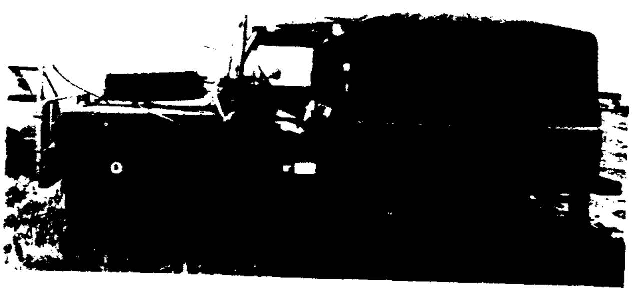


Figure 4 — TI 4100 antenna on tower extended to 21m high (Section 4.3)

Figure 5 — Kinematic relative position at Mascot Airport, Sydney (Section 6)



A United States Defense Mapping Agency (DMA) version of the precise relative positioning program, PHASER, is installed on a DEC VAX for use at the Directorate of Survey - Army in Canberra. This capability will only be utilised when it is considered that GEOMARK™ will not provide the required accuracy. This will probably only occur on 1st Order lines over 150 km in length.

5.3 Precise Absolute Point Positioning

LASTGASP is a precise absolute point positioning program developed by the Applied Research Laboratory, University of Texas for DMA. A copy of the program is now installed on a UNIVAC for use at Directorate of Survey - Army in Canberra. The program uses corrected P code pseudoranges and accumulated L1 and L2 Doppler measurements as observations. In a pre-processor, the observed receiver time is converted to transmitted time and the satellite clock correction is computed from the navigation message drift rates and applied to the time. The user then has the option of computing and applying the following corrections:

- to pseudorange and accumulated Doppler
  - earth rotation
  - satellite antenna offset
  - tropospheric refraction (2 models)
- to pseudorange only
  - pseudorange ionospheric refraction
  - time bias update
- to accumulated Doppler only
  - Doppler ionospheric refraction
  - Doppler offset

Periodic relativity is computed and applied to both the broadcast and precise ephemerides. The user may then examine the constellation Dilutions of Precision (DOPs) to decide which part of the total data set to process.

To date, only one station has been processed using LASTGASP and a summary of the results after transformation to AGD84 is in Table 12. The data span was 4.5 hours and two constellations of four satellites were used. The data has been processed using the broadcast ephemeris only. However, it is intended to process the same data using the DMA precise ephemeris.

	Latitude	Longitude	Ellipsoidal Height (ANS)
Station BLDG 200			
Terrestrial AGD84	−33° 55′ 51.″2319	151° 14′ 20.″1696	57.8m
LASTGASP 1. AGD84(a)(b)	−33° 55′ 51.″2394	151° 14′ 20.″1997	61.2m
LASTGASP 2. AGD84(a)(b)	−33° 55′ 51.″2494	151° 14′ 20.″2494	61.8m
LASTGASP 1. AGD84(a)(c)	−33° 55′ 51.″2163	151° 14′ 20.″1755	(d)
LASTGASP 2. AGD84(a)(c)	−33° 55′ 51.″2263	151° 14′ 20.″2255	(d)

Table 12 — Point Positions

Notes:

a. The two solutions are from the same data set with different processing options. PDOP's varied from 17 to 3000.

b. The transformation from WGS84 to AGD84 was by a Bursa Wolf seven parameter transformation using values in Allman *et al* 1984 for NSWC 9Z-2 to AGD84, and DMA published values for WGS84 to NSWC 9Z-2. The ANS ellipsoid height was transformed from AHD using NMC 1986.

c. The transformation from WGS84 to AGD84 was by multiple regression equations developed by DMA.

d. Height definition was uncertain so is not shown.

The RA Svy officer who undertook GPS training with DMA reports that when using the precise ephemeris, absolute positions accurate to 0.5m with respect to WGS84 should be achieveable from observation periods of 1 hour.

6.0 Kinematic Relative Positioning

The use of GPS kinematic relative positioning to determine the exposure station co-ordinates of an aerial camera is well reported.

In October 1987, RA Svy conducted a vehicle kinematic relative positioning survey at Mascot Airport, Sydney in conjunction with Dr A. Stolz of the University of New South Wales and Dr G.W. Hein of the University of Federal Armed Forces (FAF) of the Federal Republic of Germany (FRG). A static TI 4100 receiver was situated at a station of known co-ordinates at Randwick about 10 km from Mascot. The mobile antenna and receiver were mounted in a Land Rover (see Figure 5) and commenced observations at the first station to achieve 25 minutes of static tracking relative to the Randwick site. The Land Rover then travelled at 25-50 kph between the six survey points adjacent to the main north-south runway. At each station, the antenna was removed from the vehicle and placed on a pre-positioned tripod for an observation period of about 1 minute. After a return traverse to the start-point, a further ten minutes of static observations were recorded. The observed data was reduced by the University FAF.

Hein *et al* 1988 show that the maximum difference in any axis between the GPS kinematic results and the known co-ordinates was 3.5 cm. In comparison with similar tests in FRG, the Mascot test showed the following improved data characteristics: 4% versus an average 5% bad data, 23 cycle slips versus an average of 46 cycle slips.

As an extension of this vehicle test, RA Svy has initiated a test of an aircraft-mounted Total Camera Station Phase 1 (position only) based on GPS kinematic relative positioning using TI 4100 receivers. Dr G. Mader of the United States National Geodetic Survey (NGS) has offered a transfer of technology consisting of equipment interfacing details and IBM PC-based kinematic relative positioning software. The test, programmed for December 1988 to April 1989, will comprise a comparison of the GPS-derived camera position and the photogrammetric-determined position. For this purpose, a precision test range has been established in the Bandiana Military Area near the School of Military Survey. Lucas, Mader 1987 have demonstrated aircraft kinematic relative positioning accuracies of better than 20 cm (X, Y and Z). The normal RA Svy requirement for the determination of camera position for most aerial photography tasks is 1-2m.

7.0 Navigation

In October and November 1987, RA Svy supported the Royal Australian Navy Minesweeper Project by providing a TI 4100 for P code navigation. The real time navigation solutions were input to data loggers via the recorder port. The standard TI 4100 antenna. mounted atop a trawler mast, demonstrated its utility under conditions of rapid accelerations.

During the normal course of observations for static relative positioning, at least three P code navigation solutions are recorded. The navigation solutions of 42 stations in the Cooper Basin survey are summarised in Table 13.

P code navigation solutions are also used to check that the position of topographic features as portrayed on scale 1:50 000 maps is consistent with the map accuracy statement.

	AGD84/AHD — GPS Derived AGD84/AHD
PDOP range	2.9 — 5.6
Latitude	
• Maximum difference	5m
• Mean difference	3m
• Standard deviation	3m
Longitude (a)	
• Maximum difference	6m
• Mean difference	3m
• Standard deviation	1.5m
Height (b)	
• Maximum difference	18m
• Mean difference	5m
• Standard deviation	11m

Note:

a. Not including a longitude bias of approximately 30m on 22 April 1988.

b. Not including a height bias of approximately 30m on 22 April 1988.

Table 13 — Cooper Basin, Summary of Real Time Navigation Solutions

8.0 Scientific Project Observations

8.1 Orbit Determination — Australia

Since 1986, RA Svy, as a member organisation of the then National Mapping Council of Australia, has supported the University of New South Wales and Australian Surveying and Land Information Group endeavours to develop an orbit determination computation capability, although there is no defined requirement for establishing an operational capability. In order to provide suitable observation data to test the software developed by this group. RA Svy observed stations at Darwin, NT and Orroral, ACT in the period 13-19 August 1987. Other organisations conducted simultaneous observations at Townsville, Qld and Yarragadee, WA. All stations used TI 4100 receivers with input from cesium or rubidium clocks.

8.2 CASA UNO 88 Campaign

In January-February 1988, the Jet Propulsion Laboratory (JPL) co-ordinated an international program to conduct a crustal dynamic GPS survey in the Caribbean area of Central America. To provide orbit accuracies of better than 1 part in 10^{-7}, Wu *et al* 1988 proposed augmenting a continental US tracking network with stations in Hawaii, New Zealand and Australia. During the CASA UNO 88 project, RA Svy co-observed with a TI 4100 receiver at the Canberra Deep Space Communication Complex, Tidbinbilla, ACT from 18 January - 6 February 1988, to provide JPL with data for orbit determination. The TI 4100 receiver used the GESAR Version 1.5 operating system and timing input from a cesium clock. In recognition of participation in the project, JPL has offered RA Svy a copy of GIPSY (GPS Inferred Positioning System) software for precise orbit and baseline determination. Other participating nations included New Zealand, Japan, Federal Republic of Germany, Sweden, Costa Rica, Panama, Ecuador, Colombia, Venezuela and United States.

9.0 Conclusion

In the past 21 months, RA Svy has utilised its GPS manpower and equipment resources to develop training and techniques and to conduct or participate in varied projects of direct and indirect military interest. The RA Svy experience has been that the TI 4100 receivers and associated TI GEOMARK™ software are well suited to provide survey data of various accuracies in many operating environments. Exploitation of GPS will continue to be developed in the following areas: static relative positioning, static point positioning and vehicle and aircraft kinematic relative positioning for photogrammetry and surveying. In conjunction with other advanced and conventional survey systems, GPS will ensure that RA Svy is capable of providing the ADF, and in particular the field Army, with survey data for programmed and rapid response tasks in a timely and economic manner.

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