GOULBURN, NSW
AIRBORNE GEOPHYSICAL SURVEY 1996/7
OPERATIONS REPORT

by

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Australian Geological Survey Organisation
Record 1998/8

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

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Minister for Resources and Energy: Senator the Hon. W. R. Parer
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SUMMARY

The Australian Geological Survey Organisation (AGSO) flew an airborne geophysical survey of 69 500 line km covering the Goulburn 1:250 000 map Sheet area in New South Wales.

This survey, which formed part of the National Geoscience Mapping Accord, was a joint project between AGSO and the New South Wales Department of Mineral Resources. The survey was flown along east - west flight lines 250 metres apart at an altitude of 80 metres above ground level and was flown from October to December 1996 and in March 1997

The total magnetic intensity, gamma-ray spectrometric and digital elevation model data collected during the survey, have been processed and are available for purchase. These data are sold as digital point located data, grids and hardcopy maps, by the Australian Geological Survey Organisation. Colour and greyscale pixel image maps are also available.

1. SURVEY AREA AND PARAMETERS

(i) Area Description

The Goulburn airborne survey covers the Goulburn 1:250 000 map Sheet area of New South Wales. See Appendix A for a diagram of the exact survey area.

(ii) Survey Parameters

Altitude:	80 m nominal terrain clearance
Flight line direction:	East – West
Tie line direction:	North – South
Survey line spacing	
Flight line spacing:	250 metres
Tie line spacing:	2500 metres
Survey distance flown	
Lines:	62 965 km
Ties:	6 459 km
Total distance:	69 424 km
Sampling interval	
Magnetics(compensated, uncompensated and vector):	0.1 seconds (approx 7 metres)
Gamma–ray spectrometrics 4 – channel data:	1.0 seconds (approx 70 metres)
Accumulated 256 channel spectra:	1.0 seconds (approx 70 metres)
GPS:1996	1.0 seconds (approx 70 metres)
GPS:1997	0.5 seconds (approx 35 metres)
Altimeter:	1.0 seconds (approx 70 metres)
Barometric pressure:1996	10 seconds (approx 700 metres)
Barometric pressure:1997	1.0 seconds (approx 70 metres)
Temperature:1996	10seconds (approx 700 metres)
Temperature:1997	1.0 seconds (approx 70 metres)
Humidity:1996	10 seconds (approx 700 metres)
Humidity:1997	1.0 seconds (approx 70 metres)

2. LOGISTICS

(i) Operating Base and Dates of Flying

(a) Operating Base

Aircraft and crew were based at Goulburn, NSW. for the majority of the survey from 2 October to 15 December 1996, and from 6 March to 12 March 1997, and in Canberra from 27 February to 3 March 1997.

(b) Flying Dates

Calibration flights for the Automatic Aeromagnetic Digital Compensator (used to compensate for the magnetic field of the aircraft) were flown at the start of the survey, after aircraft services and installation of any new equipment. Production flying commenced on 5 October and continued until 15 December 1996. The survey was completed in the new year, with survey flying from 27 February until 12 March 1997. Appendix B summarises flying days and distances flown.

(ii) Survey Aircraft and Field Crew

(a) Aircraft

Aero Commander 500 S "Shrike", VH-BGE

(b) Field Crew

Party Leader:	Ross Franklin
Technicians:	Dave Pownall
	Peter Weber
	Trevor Dalziell
Operators:	Lars Rickardsson
	'Curly' Wilcox
	Tim Mackey
	Tony Meixner
Pilots (Pearl Aviation):	Capt. John Biffin
	Capt. Marc Bourguignon

3. SURVEY EQUIPMENT

(i) Major Equipment

Magnetometer:	Geometrics G822A caesium magnetometer
Compensator:	RMS Instruments Automatic Aeromagnetic Digital Compensator
Gamma–ray spectrometer:	Exploranium gamma–ray spectrometer consisting of a GR820 spectrum processor and two DET1024 spectrometer crystal detectors (33.56 litres total)
Altimeter:	Collins ALT–50 radar altimeter
Barometer:	AGSO digital – Setra sensor
Thermometer/Humidity:	AGSO digital – RS combined temperature and humidity sensor
Navigation:	Ashtech XII "Ranger" GPS receivers and Ashtech "Ranger" differential processing software. Fugro Omnistar Plus real time differential GPS base station system.
Doppler:1996	Racal (Decca) doppler antenna (80561 CAD) Sperry C 14 D compass
Video:	National colour video camera (WV CL 302E) National VCR (NV 180) National LCD TV (TCL 3A)
Acquisition hardware:1996	HP-A400 computer, HP9122 720 Kb 3.5 inch dual floppy disc drive and HP Thinkjet printer Compaq Notebook and 120 Mb portable hard disk drive
Acquisition hardware:1997	Axiom–Ax6150A industrial computer, 3.5 inch floppy disc drive, 504 Mb removable SCSI hard disc, IOMEGA SCSI zip drive and Planar VGA monitor.
Acquisition software:	AGSO-developed QNX C language program

(ii) Navigation

(a) GPS Navigation System

Navigation in the survey aircraft was by the real-time differential GPS method. The aircraft navigation system used an Ashtech XII global positioning system (GPS) receiver which manipulated range data received from satellites every 0.5 seconds and calculated the current latitude and longitude coordinates of the aircraft in the World Geodetic System 1984 (WGS84). The range data were recorded internally in the GPS receiver every 1.0 seconds. Differential GPS corrections to the range data, supplied by Fugro Starfix Pty Ltd, were transmitted in real time via an Optus satellite link to a Fugro OmniStar Plus base station system. The real time method employed is described more fully in Appendix C.

The real time differentially corrected position of the aircraft was recorded on the aircraft acquisition system every second (1996) or every 0.5 second (1997) and was used to provide the pilot with aircraft guidance information on an LCD display.

To enable differential GPS post flight processing, a second GPS receiver was set up at AGSO's field office caravan as a GPS base station and internally recorded range data every 1.0 seconds. The data were post processed using Ashtech 'Ranger' software at the end of each flying day. The error in position of the post processed flight path data is approximately 5-10 metres.

The position of the base station GPS receiver was accurately determined by differential GPS surveying using Mt Grey trig, located approximately 5 km north-west of Goulburn airport, as a fixed reference.

The determined base station GPS coordinates in WGS 84 were:

Longitude	:	149° 44' 00.51" E
Latitude	:	34° 48' 26.27" S
Ellipsoidal height	:	452.7 metres

The horizontal positions of the geophysical data from the survey are reported with respect to the WGS84 datum which is almost identical to the Geocentric Datum of Australia (GDA). It is intended that the GDA will be fully adopted in Australia by the year 2000. In the survey area there is an apparent translation in geographical position of 214 metres to the southwest converting from WGS84 to AGD66.

(b) Video Flight Path Recording

The aircraft's flight path was recorded on a VHS video system consisting of a National colour video camera with a wide angle lens, a National VCR and a National LCD TV.

(iii) Magnetometer

A Geometrics G822A caesium magnetometer, with the sensor mounted in a boom attached to the rear of the aircraft, was used for the survey. The specifications of the magnetometer are summarised in Appendix D.

The recorded total magnetic field data were compensated in real time using an RMS Instruments automatic aeromagnetic digital compensator (AADC). The AADC compensates for the effects of aircraft motion and heading. The specifications of the AADC are summarised in Appendix E. Compensation procedures are described in Chapter 4.

The AADC applies a low pass filter to the total magnetic field intensity data using a second order 0.9 Hz recursive Butterworth filter. The uncompensated, the filtered compensated total magnetic field intensity data and the XYZT components of the fluxgate sensor were all recorded on the aircraft acquisition system.

(iv) Gamma-ray Spectrometer

An Exploranium gamma-ray spectrometer, incorporating two DET1024 crystal detectors with a total volume of 33.56 litres, was used. The crystal gains were controlled by an Exploranium GR820 spectrum processor. Appendix F summarises the specifications of the gamma-ray spectrometer components.

Two hundred and fifty six channels of data between 0.0 MeV and 3.00 MeV were recorded every second.

Additionally five channels of data were recorded once a second using the following window limits:

Total Count	0.41-2.81 MeV
Potassium	1.37-1.57 MeV
Uranium	1.66-1.86 MeV
Thorium	2.41-2.81 MeV
Cosmic	3.00 MeV and above

The total count, potassium, uranium and thorium data were used for data quality control and the cosmic counts were used for background estimation and later data processing.

System live time (sample time - total dead time) was output with the data for later data processing.

(v) Altimeter

A Collins ALT-50 radar altimeter was used to measure ground clearance. The radar altimeter display indicates ground clearance from 0-2000 feet. The manufacturer's specifications claim a +/-2% accuracy for the ALT-50 system.

(vi) Barometer, Thermometer and Humidity

Atmospheric temperature, pressure and humidity were measured using a digital barometer (Setra sensor) and combined digital thermometer/humidity (RS sensor). Although both of these units were built by AGSO, the sensors were factory calibrated and no AGSO calibrations were performed.

(vii) Base Station Magnetometer

1996 - Daily variations of the Earth's magnetic field were monitored using a Geometrics G866 proton precession base station magnetometer, the specifications of which are given in Appendix G. The base station was set up in an area of shallow magnetic gradient, away from cultural influences and within telemetry range of AGSO's office caravan. Data from the base station were telemetered back to AGSO's field office caravan for display and recording on a Acer 486 computer. The telemetry system used AGSO-built modems incorporating Phillips 828 UHF mobile radiotelephone transmit boards at a frequency of 471.8 MHz.

Throughout the survey, base station data were recorded every twenty seconds during production flights.

1997 - Daily variations of the Earth's magnetic field were monitored using a Geometrics G–823B base station caesium magnetometer, the specifications of which are given in Appendix G. The base station was set up in an area of shallow magnetic gradient, away from cultural influences and within telemetry range of AGSO's office caravan. Data from the base station were telemetered back to the AGSO's field office caravan for display and recording on a Toshiba Pentium 110 CS lap–top computer. The telemetry system used Proxim Proxlink MSP–500 modems. The software program, "DIURNAL", developed in–house by AGSO, was used to display and log diurnal data.

Base station diurnal data were recorded at an interval of 0.1 seconds for every production and compensation flight.

(viii) Aircraft Data Acquisition

1996 - The acquisition program and system were run using a HP-A400 computer with data recorded on 3.5 inch floppy discs using a HP9122 720 Kb disc drive. The one-second multichannel spectra were recorded on a portable hard disk linked to the acquisition system through a Compaq Notebook computer.

1997 - The aircraft acquisition program and system were run using an Axiom–Ax6150A industrial 486 computer with data recorded via an IOMEGA SCSI zip drive onto 100 Mbyte zip discs.

The acquisition programs were written in the QNX C language and developed in-house at AGSO. A schematic diagram of the aircraft's acquisition systems is shown in Appendix H.

4. CALIBRATION

(i) Compensation for the Magnetic Field of the Aircraft

Compensation flights were flown in an area of low magnetic gradient prior to the start of the survey and after each aircraft service. They were flown at an altitude of 2930 m above sea level, approximately 80 kilometres northwest of Goulburn over an area between 148°25' to 118°35'E and 34°20' to 34°30'S.

The compensation procedure comprises a series of rolls(+/-10°), pitches(+/-5°) and yaws(+/-5°) in the four cardinal headings to enable the AADC to calculate correction coefficients needed to remove aircraft manoeuvre noise. Each manoeuvre component was of 30 seconds duration.

The compensation manoeuvres were repeated after calculation of the coefficients to check the compensation quality. Peak-to-peak noise during repeat manoeuvres and after the final compensation was 0.15 nT or less. On normal survey flights, noise levels from all sources were generally less than 0.15 nT peak-to-peak.

The AADC calculates basic statistics which reflect the degree of merit of the compensation. These include the standard deviation of the recorded data without corrections applied, the standard deviation with the corrections applied, the improvement ratio (the ratio of the standard deviation of the recorded data without and with the corrections applied) and the vector norm (the degree of difficulty in calculating the corrections). Examples of these statistics are given for all of the compensations in Appendix I.

(ii) Gamma-ray Spectrometer Calibration

The GR820 spectrum processor uses a sophisticated automatic control method to maintain crystal alignment while stabilising on naturally occurring isotopes (typically potassium). During operation the system continuously monitors each of the eight crystal signals and accumulates a separate spectra for each configured signal. When the confidence level for the selected stabilisation peak (potassium) is exceeded, the peak channel of this isotope is computed, compared to the correct peak location, and the gain is then corrected. The gain for each crystal was corrected at least every 30 minutes.

Gamma-ray spectrometric test lines were flown at the beginning and end of each production flight. These lines were flown at survey altitude along a dirt road approximately 10 km east northeast of Goulburn. Data were recorded for 100 seconds or approximately 6.5 km. The location of the test line used for the survey is shown in Appendix J.

Before any test line statistics were calculated the multichannel spectra were deadtime corrected, energy calibrated and background corrected using a full spectrum method (Minty, 1992). The spectra were then integrated over the conventional 4-channel windows prior to stripping and height correction.

After each flight, statistics were calculated from data recorded between fixed reference points along the test line. These statistics were recorded in spreadsheet form and compared with the preceding flights in order to detect any irregularities. In particular, the difference between the average in the total count channel for the most recently flown test line and the running average of all the previously flown test lines was analysed. This value only rarely varied by greater than 10% for the test line, well inside a 15% variation which would be considered acceptable.

5. DATA PROCESSING

Flight path recovery, data checking and editing, and preliminary processing, gridding and imaging were performed at the survey base using the Geophysical Mapping Section's INTREPID airborne geophysical data processing and visualisation system. Final magnetic, gamma-ray spectrometric and digital elevation model data processing were carried out in Canberra using INTREPID.

(i) Data Checking and Editing

Data recorded on the aircraft acquisition system were transferred on a flight by flight basis to a hard disk on a Scorpion 10/20 Sparcstation to be edited for missing values, noise, spikes or steps using INTREPID. All the recorded data were displayed for each survey line and any errors were interactively corrected. Anomalies arising from cultural influences, such as sheds, houses, fences and pipelines were usually not edited out. They were only edited out if they caused severe noise or caused the magnetometer to lose lock.

(ii) Flight Path Recovery

Range data which were recorded internally every one second on both GPS receivers were post-processed daily in the field using "Ranger" - an Ashtech proprietary program. "Ranger" calculates the corrected flight path (longitude, latitude and height) relative to the WGS84 reference ellipsoid.

At the end of each flying day the corrected longitude and latitude data calculated at one second intervals by "Ranger" were used to correct the GPS data recorded every half second on the aircraft acquisition system. As well as the standard "Ranger" corrections, other acquisition system specific corrections were applied. Position data were retained in the WGS84 coordinate system. The World Geodetic System 1984 (WGS84) coordinate system is defined in Appendix K. The full correction procedure is described in Appendix L and is outlined below:

(a) Position calculation delay correction.

(b) Fiducial synchronisation correction.

(c) "Ranger" corrections.

(d) Low pass filter.

(e) Reference navigation data to position of magnetometer sensor.

(f) Doppler infill of gaps (1996) or linear infill of gaps (1997).

The fully corrected flight path was plotted each day to check the position of survey lines and their spacing. For the survey line spacing of 250 metres navigation reflies were determined by the following criteria:

Across Track Deviation	Distance along line	GPS Data Gap
30 metres	greater than 3 km	greater than 5 km

Whenever the across track deviation and along line distance or the GPS data gap were exceeded, the survey line was reflown or an infill line flown to rectify the problem. This occurred very infrequently.

(iii) Magnetic Data Processing

Raw magnetic data were merged with the navigation data, and diurnal variation corrections were removed. The IGRF 1990 geomagnetic reference field, updated to 1996.9 at an altitude of 730 metres above sea level, which was estimated to be the mean survey altitude, was then subtracted from the data.

The IGRF was calculated from the coefficients defined by the IAGA (1991). All magnetic values were adjusted by a constant so that the average residual magnetic field value was approximately 5000 nT.

The data were levelled using standard tie line levelling procedures. Luyendyk (1997) describes the procedure involved in the tie line levelling method in more detail. The steps involved in the tie line levelling were as follows:

(a) Tie line 330 was chosen as a reference tie.

(b) All other ties were levelled to this tie using degree one polynomial adjustments.

(c) Lines were adjusted on a flight by flight basis using degree one polynomial adjustments to minimise the differences at line/tie crossover points.

(d) Finally the lines were individually adjusted using degree one polynomial adjustments to minimise crossover differences.

The data were micro-levelled using the technique described by Minty (1991). Filter characteristics are described below.

(a) Low pass filter in the flight line direction with a cut-off wavelength of 5000 metres.

(b) High pass filter in the tie line direction with a cut-off wavelength of 500 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 500 metres before being applied to the line data and were constrained to fall within the range ±20 nT. Statistics on the applied corrections indicated that 98.5% of the corrections were between ±2 nT.

The micro-levelled data were gridded with a 1.8 second (50 metre) grid cell using the minimum curvature technique described by Briggs (1974).

(iv) Gamma-ray Spectrometer Data Processing.

The 1 second multichannel spectrometer data were first corrected for system deadtime and then energy calibrated. The energy calibration technique used involves nominating a standard spectrum to which all other spectra are matched by iteratively adjusting the zero level and gain using a double quadratic minimisation technique (Minty and others, 1990).

Four-channel data were created by summing adjacent channels (from the deadtime corrected and energy calibrated multichannel data) over the conventional 4 windows (as given in Chapter 3 - Section (iv)). Background estimates for each of the four recording windows were removed. These estimates were determined as follows.

(a) Aircraft and Cosmic Background
Aircraft and cosmic spectra for the AGSO aircraft were determined from high altitude calibration flights using the procedure described by Minty and Richardson (1989).

(b) Total Background
The total background in the uranium window is the sum of the aircraft, cosmic and radon background. The total count and potassium window backgrounds were estimated directly from the uranium background since they are linearly dependent (Grasty, 1975). The thorium window was considered to be unaffected by atmospheric radon, so total thorium background was estimated from the aircraft and cosmic backgrounds. Adjustments for radon effects in the other channels were made at the end of the processing sequence.

The data were corrected for height attenuation and reduced to a nominal flying height of 80 m. Where the aircraft attained a height of 250 m or higher above the ground gamma-ray spectrometric data have been set to undefined. Height attenuation corrections were made using the following formula

$$N_{corrected} = N_{uncorrected}\, e^{-u(H-h)}$$

where

$N_{corrected}$ = corrected counts

$N_{uncorrected}$ = uncorrected counts

H = nominal flying height

h = measured flying height

u = attenuation coefficient

Attenuation coefficients for each channel are given below

$u_{total\ count} = 0.006354$

$u_{potassium} = 0.009084$

$u_{uranium} = 0.005967$

$u_{thorium} = 0.006145$

Channel interaction corrections (stripping) to correct for Compton scattering were then applied to the data. Stripping ratios for the AGSO system were determined by Minty and others (1990) using portable calibration sources. The corrections were applied as follows

$$N_{TH(corrected)} = N_{TH}$$
$$N_{U(corrected)} = N_U - A \times N_{TH(corrected)}$$
$$N_{K(corrected)} = N_K - B \times N_{TH} - C \times N_{U(corrected)}$$

where

N_{TH} = counts in the thorium channel

N_U = counts in the uranium

N_K = counts in the potassium channel

A = 0.447 + 0.00046*height

B = 0.399 + 0.00107*height

C = 0.832 + 0.00109*height

Gamma-ray spectrometric data were levelled in much the same way as the magnetic data. However, prior to sampling the crossover points, a 5 point convolution filter was passed over the data. Note that these filtered data were only used for the crossover analysis and the final point located data have not been filtered. The steps involved in the tie line levelling were as follows:

(a) Tie line 330 was chosen as a reference tie.

(b) All other ties were levelled to this tie line using degree one polynomial adjustments.

(c) Lines were adjusted on a flight by flight basis using degree one polynomial adjustments to minimise the differences at line/tie crossover points.

(d) Finally the lines were individually adjusted using degree one polynomial adjustments to minimise crossover differences.

The data were micro-levelled using the technique described by Minty (1991). Filter characteristics are described below.

(a) Low pass filter in the flight line direction with a cut-off wavelength of 5000 metres.

(b) High pass filter in the tie line direction with a cut-off wavelength of 1000 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 500 metres before being applied to the line data. Adjustments were limited to a maximum of 250, 20, 10 and 10 counts/sec for Total Count, Potassium, Uranium and Thorium channels respectively. Statistics on the applied corrections indicated that 92.3%, 93.5%, 97.7% and 97.5% of the corrections were less than 100, 10, 5 and 5 counts/sec for Total Count, Potassium, Uranium and Thorium respectively.

Potassium, uranium, and thorium data are reported as equivalent concentrations on the ground (%K, ppm eU, and ppm eTh). The sensitivity factors required to convert the airborne count-rates to elemental concentrations on the ground are determined from test flights over an airborne calibration range. The conventional 'total count' is converted to estimates at ground level of the air-absorbed dose-rate (in nG/hr) due to natural sources of radiation. The corrected elemental count rates were converted to ground concentrations of K, U and Th using the expression:

$$C = \frac{N}{S}$$

where

C = concentration of the radioelement (K%, U ppm or Th ppm);
S = broad source sensitivity for the elemental count rate; and
N = the fully processed elemental count rate (cps).

The broad source sensitivities were obtained from flights over a calibration range. The following sensitivities were used:

Potassium:	377.74 cps/%K
Uranium:	108.07 cps/ppm eU
Thorium:	56.63 cps/ppm eTh.

The total count was converted to the equivalent air-absorbed dose rate at ground level using the expression:

$$D = \frac{N}{F}$$

where

D = the air absorbed dose rate (nGh^{-1});
F = the conversion factor determined experimentally from flights over a calibration range (23.14 cps/nGh^{-1}); and
N = the total count rate (cps).

The four channels of micro-levelled data were gridded with a 1.8 second (50 metre) grid cell using the minimum curvature technique described by Briggs (1974).

(v) Digital Elevation Model Data Processing

As described in Chapter 5 — Section (ii), range data recorded internally every one second on both GPS receivers were post—processed on a daily basis using "Ranger" — an Ashtech proprietary program. "Ranger" calculates the position of the aircraft GPS receiver's antenna, including longitude, latitude and height relative to the WGS84 reference ellipsoid for each set of range data (every one second).

As in the case of the longitude and latitude data, the following acquisition system specific corrections, which are described in Appendix L, are applied to the height data.

(a) Position calculation delay correction.

(b) Fiducial synchronisation correction.

The corrected height data, which are relative to the WGS84 reference ellipsoid, are then linearly interpolated to one second samples (1996) or one half of one second samples (1997) and merged with the longitude and latitude data.

A radar altimeter provided the aircraft's ground clearance, the altimeter data being sampled every one second.

The raw ground elevation data were then calculated as the difference between the height of the aircraft above the ellipsoid and the height of the aircraft above the ground. These raw elevation data calculated every one second (70 m along the ground) are relative to the WGS84 reference ellipsoid - the ellipsoid being a horizontal datum.

The next step was to convert the heights relative to the WGS84 ellipsoid to heights relative to the geoid. The geoid, which is defined as "the equipotential surface of the gravity field which best approximates mean sea level", is usually chosen as the datum to which heights plotted on maps are referred. The height of the geoid above the WGS84 ellipsoid is called the geoid-ellipsoid separation or N value.

Geoid-ellipsoid separation information for the Goulburn Sheet area were as supplied by the Australian Surveying and Land Information Group (AUSLIG). The set of N values were supplied as a 10 minute of arc (approximately 18 km) grid. AUSLIG also provides a program "DINTER" which uses bilinear interpolation to calculate N values on a one minute of arc (approximately 1 600 metre) grid. These values were then regridded to a cell size of 12 seconds of arc (approximately 320 metres). This grid of N values was then used to calculate correction strings to be subtracted from the elevation data. The correction strings were low pass filtered with a cut-off wavelength of 1 000 metres before being applied to the point-located elevation data.

The elevation data were then corrected to account for the vertical separation between the antenna of the aircraft's GPS receiver, on the roof of the aircraft, and radar altimeter on the belly of the aircraft. This antenna separation distance of 1.675 metres was also subtracted from the elevation data.

The elevation data were levelled using tie line information and then micro-levelled.

The steps involved in the tie line levelling were as follows:

(a) Tie line 330 was chosen as a reference tie.

(b) All other ties were levelled to the reference tie using degree one polynomial adjustments.

(c) Lines were adjusted on a flight by flight basis to minimise the differences at line/tie crossover points, using degree one polynomial adjustments.

(d) Finally the lines were adjusted individually to minimise crossover differences, using degree one polynomial adjustments.

The data were micro–levelled using the technique described by Minty (1991). Filter characteristics are described below.

(a) Low pass filter in the flight line direction with a cut-off wavelength of 5 000 metres.

(b) High pass filter in the tie line direction with a cut-off wavelength of 500 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 500 metres before being applied to the position located data. Adjustments were limited to a maximum of 5 metres. Statistics on the applied corrections indicated that 96.9% of the corrections were less than 5 metres.

The accuracy of the position located height data should be better than +/-10 metres. Relative precision from point to point along a flight line is expected to be better than +/-5 metres.

The micro-levelled data were gridded using Briggs (1974) minimum curvature technique with 1.8 second (50 metre) grid cell size.

(vi) Final Products

(a) Standard AGSO geophysical maps

An AGSO standard set of geophysical maps have been produced at scales of 1:250 000 and 1:100 000 for the Goulburn Sheet. Flight path and contour maps were produced using the INTREPID processing system. The standard set of maps produced are shown in Appendix M.

(b) Digital Data

Final processed point-located data and grids were archived in the standard AGSO ARGUS format, on exabyte magnetic tape cartridges and compact discs, in ASCII format (Appendix N).

(c) Pixel Image Maps

Additional to the standard AGSO geophysical maps listed in Appendix M, pixel image maps have been compiled using the method described by Milligan and others (1992). The following pixel image maps have been released:

(a) Colour 1:250 000 scale image of total magnetic intensity reduced to the pole with illumination from the north.

(b) Greyscale 1:250 000 scale image of fractional vertical derivative of total magnetic intensity reduced to the pole.

(c) Colour 1:250 000 scale composite image of airborne gamma-ray spectrometry - Red (Potassium), Green (Thorium), Blue (Uranium).

(d) Colour 1:250 000 scale image of digital elevation model with illumination from the north-east.

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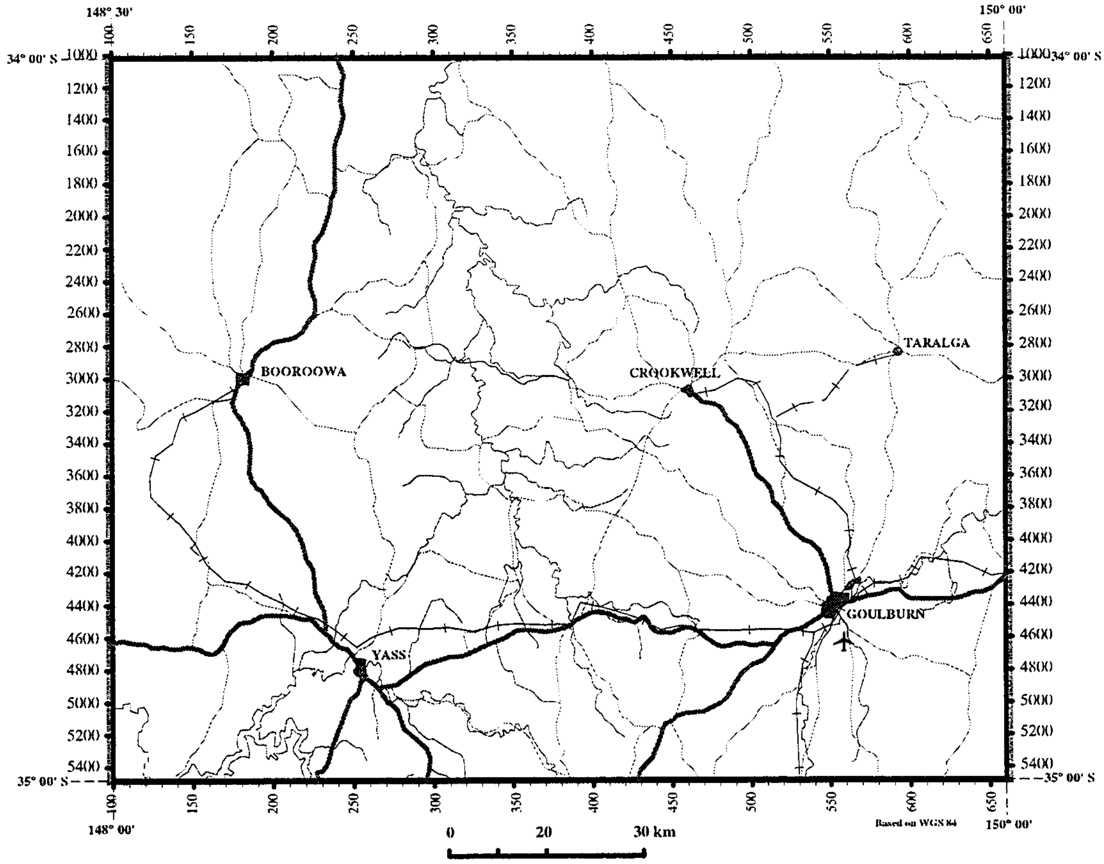
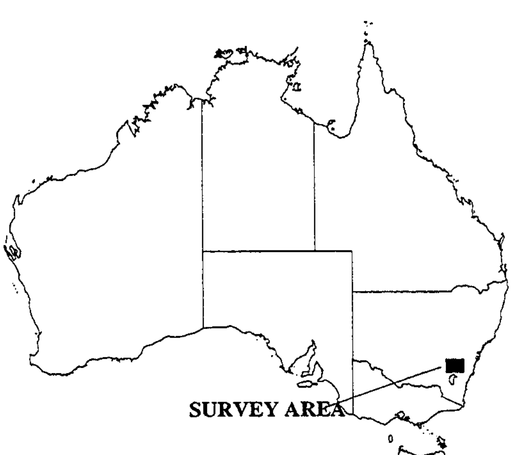
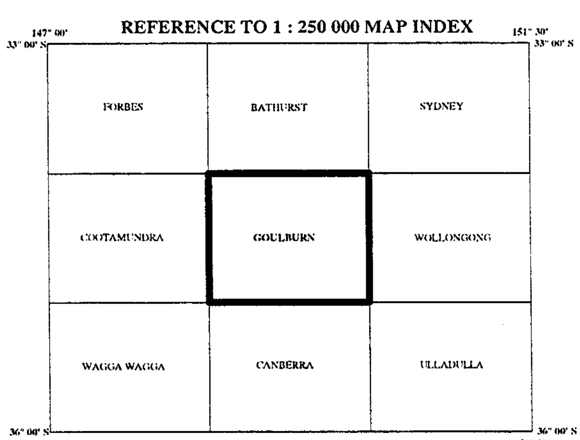
APPENDIX A

Survey Area



GOULBURN 1996 SURVEY P650





APPENDIX B-1

Flying Dates and Line Kilometres Flown

DATE	FLIGHT NUMBER	COMMENTS	LINE / TIE KILOMETRES
05/10/96	387	Compensation #1	
05/10/96	388	Flight abandoned - low cloud	280
05/10/96	389	Operations normal	840
07/10/96	390	Altimeter Check	
08/10/96	391	Operations normal	840
08/10/96	392	Operations normal	840
09/10/96	393	Flight abandoned - wind	560
13/10/96	394	Operations normal	840
13/10/96	395	Operations normal	840
14/10/96	396/7	Operations normal	840
14/10/96	398	Flight abandoned - wind	560
15/10/96	399	Operations normal	840
15/10/96	400	Operations normal	840
19/10/96	401	Flight abandoned - wind	560
21/10/96	402	Operations normal	840
21/10/96	403	Operations normal	840
22/10/96	404	Operations normal	840
22/10/96	405	Operations normal	840
23/10/96	406	Operations normal	840
23/10/96	407	Operations normal	840
24/10/96	408	Operations normal	840
24/10/96	409	Operations normal	840
25/10/96	410	Operations normal	720
25/10/96	411	Flight abandoned - wind	560
26/10/96	412	Operations normal	840
26/10/96	413	Flight abandoned - low cloud	280
28/10/96	414	Operations normal	840
28/10/96	415	Operations normal	840
29/10/96	416	Flight abandoned - wind	560
30/10/96	417	Flight abandoned - wind	560
31/10/96	418	Operations normal	840
31/10/96	419	Operations normal	840
01/11/96	420	Operations normal	840
01/11/96	421	Operations normal	840
02/11/96	422	Operations normal	840
02/11/96	423	Operations normal	840
03/11/96	424	Operations normal	840
03/11/96	425	Operations normal	840
04/11/96	426	Operations normal	840
06/11/96	427	Operations normal	840.
06/11/96	428	Operations normal	840
07/11/96	428	Operations normal	840
11/11/96	429	Compensation #2	
11/11/96	430	Flight abandoned - geo equip	560
13/11/96	431	Flight abandoned - wind	280
14/11/96		Flight abandoned - wind	
15/11/96	432	Operations normal	840

APPENDIX B-2

Flying Dates and Line Kilometres Flown

DATE	FLIGHT NUMBER	COMMENTS	LINE / TIE KILOMETRES
16/11/94	433	Operations normal	840
16/11/96	434	Operations normal	840
19/11/96	435	Operations normal	840
19/11/96	436	Operations normal	840
20/11/96	437	Operations normal	840
20/11/96	438	Operations normal	840
21/11/96	439	Operations normal	840
21/11/96	440	Operations normal	420
21/11/96	441	Operations normal	420
24/11/96	442	Operations normal	700
24/11/96	443	Operations normal	840
25/11/96	444	Operations normal	840
25/11/96	445	Operations normal	840
26/11/96	446	Operations normal	840
26/11/96		Flight abandoned - wind	
27/11/96	447	Operations normal	840
29/11/96	448	Operations normal	840
30/11/96	489	Flight abandoned - ac equip	630
01/12/96	450	Operations normal	840
03/12/96	451	Operations normal	840
03/12/96	452	Flight abandoned - wind	210
04/11/96	453	Operations normal	840
04/11/96	454	Operations normal	840
05/11/96	455	Operations normal	630
05/12/96	456	Flight abandoned - wind	280
06/12/96	457	Flight abandoned - wind	455
08/12/96	458	Flight abandoned - ac equip	345
08/12/96	459	Operations normal	635
09/12/96	460	Flight abandoned - wind	280
10/12/96	461	Operations normal	875
10/12/96	462	Operations normal	840
11/12/96	463	Operations normal	840
11/12/96	464	Operations normal	840
12/12/96	465	Operations normal	840
12/12/96	466	Operations normal	830
13/12/96	467	Operations normal	840
14/12/96	468	Operations normal	840
14/12/96	469	Operations normal	840
19/02/97	133	Compensation #3	
21/02/97	134	Altimeter check	
24/02/96	135	Flight abandoned - geo equip	280
25/02/96	136	Operations normal	510
26/02/97	137	Flight abandoned - wind	350
27/02/97	138	Operations normal	500
28/02/97	139	Operations normal	560
01/03/97	140	Operations normal	500

APPENDIX B-3

Flying Dates and Line Kilometres Flown

DATE	FLIGHT NUMBER	COMMENTS	LINE / TIE KILOMETRES
01/03/97	141	Operations normal	660
05/03/97	142	Operations normal	660
06/03/97	143	Flight abandoned - geo equip	
07/03/97	144	Flight abandoned - wind	440
07/03/97	145	Operations normal	670
08/03/97	146	Operations normal	880
08/03/97	147	Operations normal	880
10/03/97	148	Operations normal	660
10/03/97	149	Operations normal	660
11/03/97	150	Operations normal	660
11/03/97	151	Operations normal	640
12/03/97	152	Operations normal	700
12/03/97	153	Operations normal	560

Total line/tie kilometres flown 24390

Total flights in survey 106

- Productive survey flights 98
- Unproductive survey flights 8
- Abandoned flights 22

Unproductive survey flights consisted of:

- Weather 2
- Compensation flights 3
- Test flights 3

Abandoned survey flights consisted of:

- Weather 17
- Equipment malfunction - aircraft 2
- Equipment malfunction - geophysical 3

APPENDIX C
REAL TIME DIFFERENTIAL GPS

Real time differential GPS navigation is a method used to improve navigation accuracy. Line tracking using this method is more precise than by the single GPS receiver method thus allowing a pilot to fly an aircraft to an accuracy of better than 5 m.

The navigation equipment used for this survey consisted of two Ashtech XII GPS receivers; one at a known position on the Goulburn airfield where the office caravan was located, and the other in the aircraft. The ground based GPS receiver operated in non-differential mode while the aircraft GPS receiver was configured to run in differential mode.

Fugro Starfix Pty. Ltd. supplied the satellite range corrections to the aircraft. The range corrections were calculated using Fugro's OmniSTAR Wide Area Differential GPS (WADGPS) service. OmniSTAR is a differential GPS service over Australia which is supported by a network of reference stations located throughout the continent to provide differential GPS corrections back to Fugro's Network Control Centre (NCC) in Perth. The WADGPS service allows monitoring of data from more than one reference station, quality control parameters, weighted least squares solution and improved accuracy over a single reference station

The range corrections from all the available reference stations are transmitted to the NCC in Perth, then to an OmniSTAR Plus - Enhanced Differential System (EDS) receiver in the aircraft via the Optus satellite. The EDS receiver contains a demodulator board, an eight channel GPS engine, a computing engine and an interface and power supply board. The OmniSTAR Plus demodulator receives the Fugro compressed data from the satellite and using the aircraft's position and the "least squares method" computes an optimum set of RTCM (Radio Technical Commission for Maritime Services) corrections for ouput to the aircraft GPS receiver. The EDS receiver calculates the aircraft position from the internal GPS engine and then provides corrections for output to the aircraft GPS receiver in RTCM 104 format.

The EDS receiver gets satellite range data and range correction data through an OPTUS plate antenna on the roof of the aircraft. The Ashtech GPS receiver in the aircraft uses an Ashtech plate antenna for receiving satellite range data. The EDS receiver outputs corrections to the aircraft GPS receiver at 4800 baud.

APPENDIX D

SPECIFICATIONS - G822A CESIUM MAGNETOMETER

Operating principle:	Self-oscillating cesium vapour magnetometer
Operating range:	20,000 to 95,000 nT
Active Zones:	Sensor equator ±10° H_o field sensor axis ±10°, switchable or auto switch
Noise level:	<= 0.01 nT peak-to-peak
Heading error:	<= ± 0.25 nT, <= 0.5 nT envelope
Power required:	26 to 32 VDC, 500 mA continuous, 750 mA while starting
Output:	2V p-p, f (Hz) = 3.498 H_o (nT)
Inerface:	Larmor signal AC coupled to power input
Environmental:	-35 °C to +50 °C, humidity 95% non-condensing
Dimensions:	Sensor: 5 cm diameter, 18 cm long, 140 grams Electronics module: 5 cm wide, 5 cm high, 23 cm long 170 grams Sensor electronics cable: 135 cm to 270 cm long
Qualification:	MIL-I-45208, MIL-M-19595

APPENDIX E-1

Specifications - RMS Instruments
Automatic Aeromagnetic Digital Compensator

INPUTS:	one or two high sensitivity magnetometers of optical absorption type.
INPUT FREQUENCY RANGE:	70 KHz - 350 KHz - Cs sensor 140 KHz - 700 KHz - K sensor 560 KHz - 2800 KHz - He sensor 850 Hz - 4260 Hz - Overhauser
MAGNETIC FIELD RANGE:	20,000 - 100,000 nT (gamma)
RESOLUTION:	1 pT (picotesla)
COMPENSATION PROCEDURE:	improvement ratio 10 - 20 typical for total field improvement ratio 20 - 100 typical for gradient
ACCURACY OF COMPENSATION:	0.035 nT (gamma) standard deviation for the entire aircraft flight envelope in the bandwidth 0 - 1 Hz typical
DATA OUTPUT RATE:	10 Hz
SYSTEM FREQUENCY RESPONSE:	0 - 0.9 Hz
INTERNAL SYSTEM NOISE:	less than 2 pT (standard deviation in the bandwidth 0 - 1 Hz)
DURATION OF CALIBRATION: FLIGHT MANOUEVRES	5 - 8 minutes typical
VECTOR MAGNETOMETER:	Develco Model 9202-02 (3-axis fluxgate)
MICROCOMPUTER:	SBC-11/21 Plus (DEC) Front End LSI-11/73 (DEC) Main CPU
KEYBOARD:	limited alphanumeric
DISPLAY:	green fluorescent, 80 character self scan panel
OUTPUTS:	serial data communication port: RS232C - max. rate 19.2 K Baud parallel output port: 16 bit with full handshaking (DRV11-J) (optional)

APPENDIX E-2

Specifications - RMS Instruments Automatic Aeromagnetic Digital Compensator

POWER:	28 +/- 4 VDC, 5A, 150 W (for single magnetometer) 7A, 196 W (for gradiometer system)
ENVIRONMENTAL:	
OPERATING TEMPERATURE:	0 to 50 degrees C
STORAGE TEMPERATURE:	-20 to 55 degrees C
RELATIVE HUMIDITY:	0 - 99%, non-condensing
ALTITUDE:	0 - 6000 m (0 - 20,000 ft)
PHYSICAL DATA:	console dimensions: 483 x 178 x 440 mm console weight: 12.5 kg power supply dimensions: 225 x 180 x 220 mm power supply weight: 5.5 kg

APPENDIX F-1

SPECIFICATIONS - GR820 SPECTROMETER SYSTEM

A. Detector Controller

- Maximum number of crystals - 16. Each crystal has individual pole-zero cancellation, semi-gaussian shaping and advanced base line restoration circuitry.
- Continuous, individual-crystal spectrum analysis ensures that optimum system stabilization is achieved. Resolution is calculated by a sophisticated gaussian curve fitting algorithm to perform an accurate centroid analysis of the selected stabilization peak.
- High energy cosmic pulses are accumulated in a separate channel.
- Accurate pile-up rejection for simultaneous pulses allows qualitative gamma-ray spectrum analysis almost independent of the system count rate. Special circuitry analyzes for pulse pile-up and permits only detector signals from single events to be analyzed. Simultaneous events in adjacent crystals are added to reduce the Compton effect.
- Residual pulse pile-up at 100,000 counts/sec are less than 2%.

B. Analog to digital converter (ADC)

- 50 mhz Wilkinson ramp ADC.
- Linearity - integral - less than 0.2% - differential - less than 1%.
- Average system dead-time is less than 5 microseconds/pulse.
- Live-time channel records the actual system live-time. This data is output with the digital data which allows post correction for system dead-time to an accuracy of 0.1%.
- Number of channels - selection of 256 channels or 512 channel operation.
- Maximum number of counts/channel - 65,535 (16 bits).
- The lower threshold - manually selectable from channel 2 to channel 50 (20-500 kev).
- The upper threshold is set to 3 Mev. All pulses above 3 MeV are accumulated in the cosmic channel as a direct measure of cosmic ray activity.
- ADC offset set from the keyboard.
- The maximum input count rate is 100,000 counts/second.

C. System outputs

- Visual display - the front panel display is a 640x200 electroluminescent (EL) high contrast graphics display which allows full spectrum display, system set-up and various parameter monitoring functions. In the spectrum display mode, the region of interest and cursor may be viewed by channel number or directly in keV.
- The internal channel number to energy level (keV) conversion table compensates for non-linearity of the detector's light output.
- The front panel has a 21 button keyboard for easy operator control.
- The system's operation is fully menu driven.
- Digital outputs
    - RS-232 port (1200 to 19200 baud).
    - IEEE-488 bus output - talk lisn/talk only.
    - Geometrics GR-800 output format.
    - Some system functions can be controlled remotely by an external computer via the RS-232 and the IEEE-488 digital ports.
- Anolog output
    - 4 channels of roi data can be selected for output on the analog port. The outputs have 10 bit resolution (0-10V). Scaling can be set from the keyboard (100-50K counts/sec FSD) and output data may be raw or stripped using internally stored calibration constants. Analog output wraps at fsd limits and is dead-time corrected.

D. Miscellaneous

- Regions of interest (ROI) 8 ROIs can be selected. The upper and lower thresholds can be individually set over the entire spectrum range.
- The first 4 ROIs are available for digital and analog output. The second 4 rois are available only for digital output on the RS-232 or the IEEE-488 ports.
- System resolution. Detector resolution is automatically computed for each (and summed crystals) during peak analysis and is displayed for operator monitoring when required. The summed down resolution is also output on the data stream.

  System test. At power on, a full system test of all internal pcb handshaking is performed. Included in the testing is the lithium back-up battery, the system ram memory, display handshaking, the systems configuration (options installed), the selected detectors (checked via ADC analysis) and peripheral handshaking response.

- Configuration menus. The configuration menus allow the selection of the number of detectors in use, confidence levels for gain analysis, maximum crystal resolution levels for each detector (with operator warning if levels exceeded), output configurations for analog and digital data and various special display/monitoring functions.
- Maintenance. A set of special menus allows the user to test and calibrate many system functions including system test, ADC offset, low level discriminator etc.
- Power : 28V - 1.25 amps

E. Detectors

The crystals are housed in specially designed hi-impact polystyrene cases using low background materials for minimum signal attenuation. Full thermal and internal shock protection allows the units to be directly mounted to the floor. A very low noise, high voltage power supply is housed in each pack so high voltage is not present in the connecting cables. A unique preamplifier with special processing for signal optimization is used. The GPX-1024 has 4 crystals with a total volume of 16.78 litres

- Outputs. Individual BNC connectors output each crystal's signal separately.
- Size : GPX-1024 : 73x51x30 cms)
- Weight : GPX-1024 : 84 kg
- Power : 28 V @ 0.5 A/crystal pack
- Temperature limitations

  Closed pack : storage -40 to +60, operation -40 to +60 deg. C

  Open pack : not recommended

  Temperature gradient

  Closed pack : -40 to +50 (instantaneous)

  Open pack : a change of 1 deg. C/hr.

APPENDIX G-1

SPECIFICATIONS - G833 HELIUM BASE STATION MAGNETOMETER (1996)

Operating range:	20,000 to 95,000 nT
Temperature:	-20 to +50 °C
Sensitivity:	0.0032 nT/root Hz RMS
Bandwidth:	350 Hz (-3dB point)
Loop scan rate:	1000 cycles/second
Input power:	28 V DC, 6 A max
Output signal:	At He gyromagnetic frequency, approximately 28.02468 Hz/nT. Three volts peak to peak
Dimensions:	Sensor cell - 80 mm diameter x 145 mm length Scan processor - 270 x 120 x 85 mm Control panel - 49.26 cm rack mount
Weight:	approximately 6 kg

APPENDIX G-2

SPECIFICATIONS - MAGELLAN OEM GPS MODULE (1996)

Operational Characteristics

Position Update Rate:	1 second continuous (approximate)
Time to First Fix	
Warm Start: (with almanac/date/time/ initial position and ephemeris < 2 hours old)	30 seconds (approximate)
Cold Start: (with almanac/date/time/initial position)	75 seconds 2D/3D 9 approximate)
Autonomous start: (no almanac/ephemeris/date/ time/initial position)	5 - 12 minutes typical

Position Accuracy *
(HDOP < 2, C no > 47 db-Hz, 2D)

Horizontal Position:	25 metres RMS in 2D 30 metres RMS in 3D
Vertical Position:	50 metres RMS

* with Selective Availability disabled

Electrical Characteristics

Power:	
OEM/PS:	9 - 16 VDC 235 mA at 12 VDC typical, 250 mA max
OEM/5V:	5 VDC +/- 0.2 VDC 170 mA
Interfaces:	RS232
Baud Rates:	Jumper - selectable 1200,2400,4800,9600
Receiver Type:	4 channels dedicated to tracking satellites 1 channel dedicated to tracking all other satellites in the sky

Firmware Functions

Timing:	Timing pulse ON/OFF UTC or GMT reference Time only mode Single satellite timing default all modes Hour,minute,second,day,month,year Status indicator Satellites in solution Signal Quality

OEM Antenna	Active Quadrifilar Helix

APPENDIX G-3

SPECIFICATIONS - GT100 UNIVERSAL COUNTER (1996)

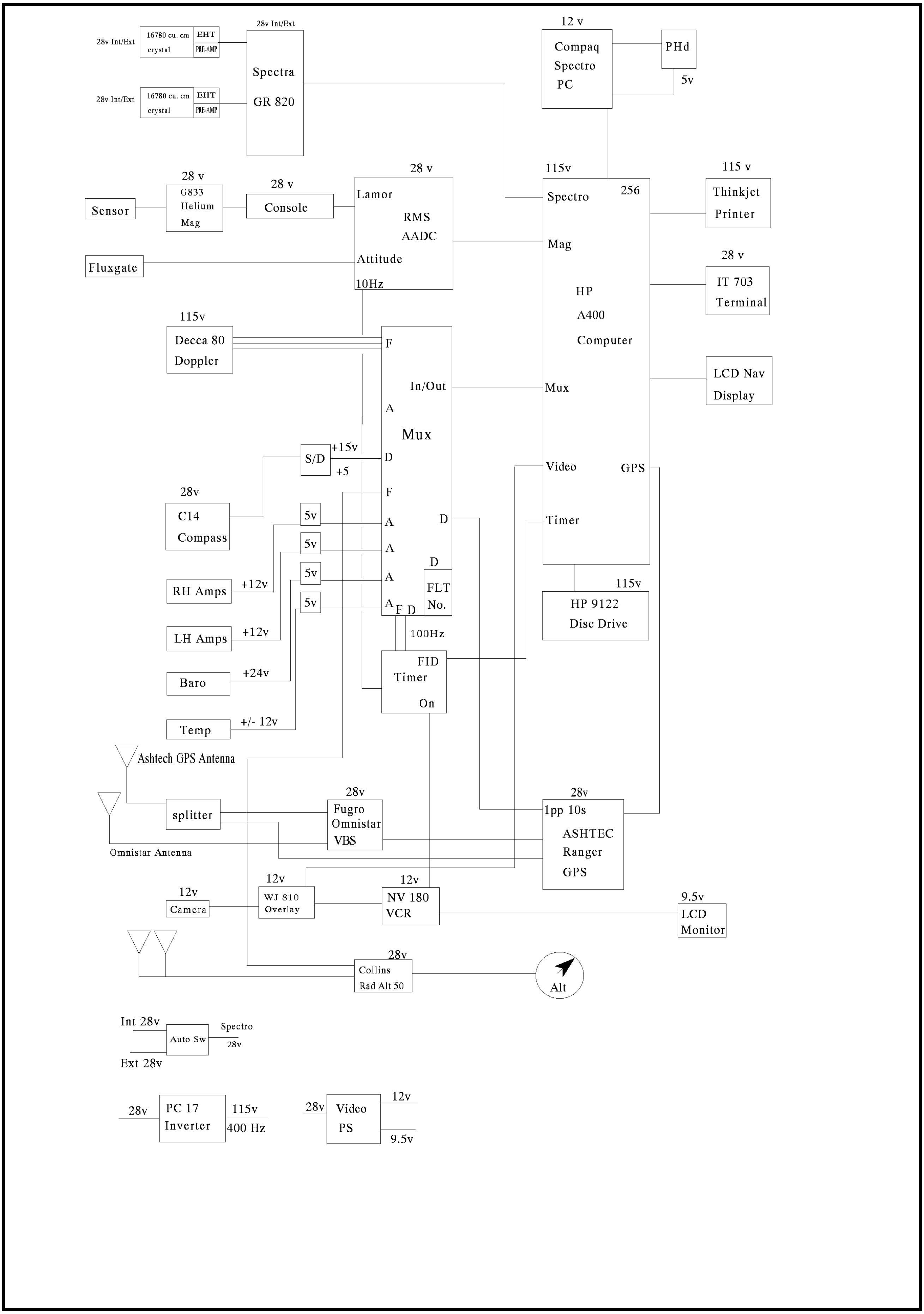
Input Characteristics			
Channels A and B			
Frequency Range:	DC to 100 Mhz		
Signal Operating Range:	+5 V to -5 V		
Sensitivity:	Sinewave	25 mV RMS Dc to 20 Mhz	
		50 mV RMS 20 Mhz to 50 Mhz	
		160 mV RMS 50 Mhz to 100 Mhz	
	Pulse	450 mV pk-pk at 5 ns pulse width	
Measurement Functions			
Resolution: (in Hz)	+/- LSD +/- Freq *1.4 *Trigger Error/Gate time		
Accuracy: (in Hz)	+/-Resolution +/- Time Base Error		
General			
Compatibility:	1 full size slot in any PC/XT, PC/AT or compatible, using DOS 3.0 or higher. Compatible with any programming language.		
Time Base:	Standard 10 Mhz Crystal Oscillator Accuracy +/- 100 ppm (0.01 %)		

APPENDIX G-4

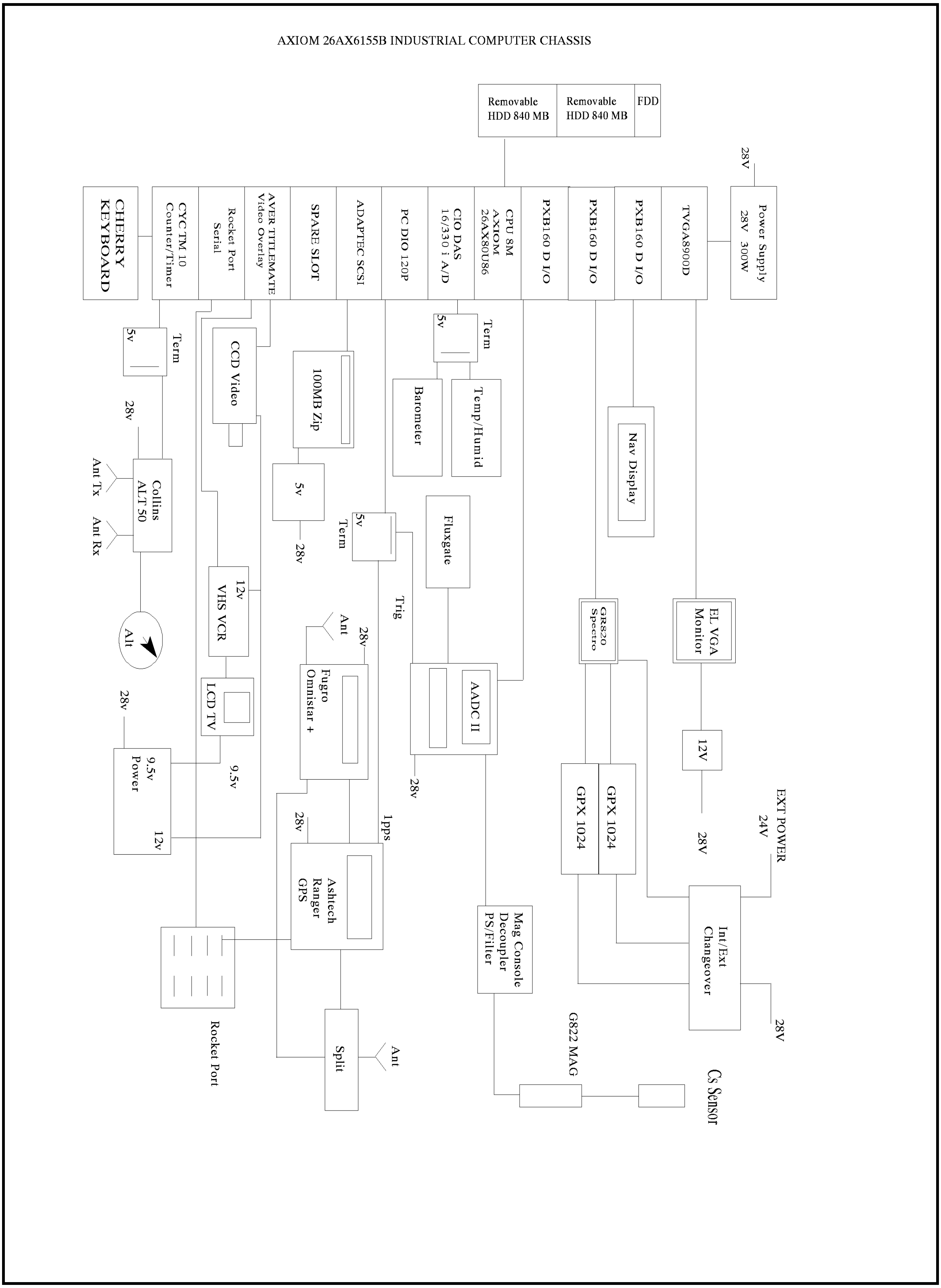
SPECIFICATIONS - G823B CAESIUM BASE STATION MAGNETOMETER (1997)

Operating principle:	Self-oscillating caesium vapour magnetometer
Operating range:	20,000 to 95,000 nT
Active Zones:	Sensor equator ±10° H_o field sensor axis ±10°, switchable or auto switch
Noise level:	<= 0.01 nT peak-to-peak
Heading error:	<= ± 0.25 nT, <= 0.5 nT envelope
Power required:	26 to 32 VDC, 500 mA continuous, 750 mA while starting
Output:	2V p-p, f (Hz) = 3.498 H_o (nT)
Interface:	Larmor signal AC coupled to power input
Environmental:	-35 °C to +50 °C, humidity 95% non-condensing
Dimensions:	Sensor: 5 cm diameter, 18 cm long, 140 grams Electronics module: 5 cm wide, 5 cm high, 23 cm long 170 grams Sensor electronics cable: 135 cm to 270 cm long
Qualification:	MIL-I-45208, MIL-M-19595

APPENDIX H AIRCRAFT ACQUISITION SYSTEM - 1996



APPENDIX H AIRCRAFT ACQUISITION SYSTEM - 1997



APPENDIX I-1

Compensation Results

COMPENSATION 1.   Date flown: 5 October 1996

Air conditioner off	SDU	=	0.1787
	SDC	=	0.01729
	IR	=	10.3
	VN	=	1.2
Air conditioner on	SDU	=	0.1801
	SDC	=	0.05431
	IR	=	3.2
	VN	=	6.9

COMPENSATION 2.   Date flown: 11 November 1996

Air conditioner off	SDU	=	0.1738
	SDC	=	0.01700
	IR	=	11.4
	VN	=	0.51
Air conditioner on	SDU	=	0.1937
	SDC	=	0.05461
	IR	=	3.2
	VN	=	6.0

COMPENSATION 3.   Date flown: 19 February 1997

Air conditioner off	SDU	=	0.2143
	SDC	=	0.02770
	IR	=	7.7
	VN	=	26.7
Air conditioner on	SDU	=	0.2494
	SDC	=	0.04251
	IR	=	5.9
	VN	=	24.3

SDU = Standard deviation of the data recorded during manoeuvres.

SDC = Standard deviation of the data recorded during manoeuvres after compensation corrections have been applied.

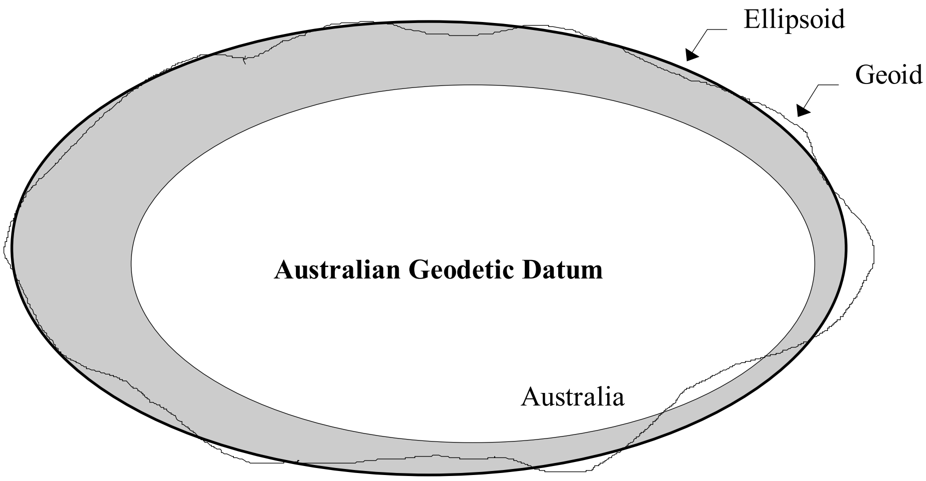
IR = Improvement ratio = SDU / SDC

VN = Vector Norm, a measure of the degree of difficulty in calculating the coefficients.

APPENDIX K

The Australian Geodetic Datum

For geophysical surveys the real shape of the earth has to be considered. An ellipsoid of revolution around the earth's north-south axis approximates the earth's shape. This figure is called the spheroid. The mean sea level equipotential surface describing the shape of the earth is known as the geoid.



Calculated positions from the GPS are in the World Geodetic System 1984 (WGS84). The WGS84 datum is a global geocentric reference datum that has as its origin the Earth's centre of mass. The non-geocentric datum which comprises the Australian National Spheroid (ANS) is oriented and located in such a manner as to "best-fit" the geoid over the Australian continent.

The WGS84 datum is almost identical to the Geocentric Datum of Australia (GDA). It is intended that the GDA will be fully adopted in Australia by the year 2000.

The WGS84 datum is defined by a semi-major axis (a) and flattening (f) of the selected ellipsoid.

$$a = 6378137 \text{ m}$$
$$f = 1/298.2572$$

There is an apparent translation in geographical position over the survey area of 206 metres when converting from WGS84 to AGD66.

APPENDIX L

Corrections to Differential GPS Navigation Data

(a) Position calculation delay correction

A correction due to the finite time taken for the GPS system to calculate a position and transfer the information to the acquisition system. A delay of 0.6 seconds has been determined for calculations using up to eight satellites by flying clover leaf patterns over a reference point. This value is considered to be representative and was used for all delay corrections.

(b) Fiducial synchronisation correction

A correction due to the time lag between when a GPS position is available to the acquisition system and when the next fiducial is available to pair the position with.

(c) "Ranger" corrections

Using the range data which are recorded internally on both GPS receivers every five seconds, "Ranger" calculates the correct positions at five second intervals along the flight path. These corrected positions are utilised when correcting the aircraft raw position data which are recorded every second.

Discontinuities (steps) sometimes occur in raw GPS data. These are also manifested as steps in the correction set.

When such steps in the raw GPS data occur between successive correction values, the corrections are linearly interpolated to the step boundary using corrections from the appropriate side of the step.

If multiple steps in the raw GPS data occur between successive correction values it is impossible to interpolate corrections over this interval, in which case the intervening GPS data are set to undefined.

(d) Low pass filter

The problem described in (c) can lead to small steps in the data where the original steps were too small to detect so were not corrected. A low pass 11 point convolution filter with a cut-off wavelength of 300 m was passed over the data.

(e) Reference navigation data to position of magnetometer sensor

The calculated GPS positions refer to the position of the GPS receiver's antenna. Since the magnetometer is the most position sensitive instrument, all position data is shifted 11.4 meters toward the rear of the aircraft to correspond with the position of the magnetometer's sensor.

(f) Doppler infill of gaps (1996) or linear infill of gaps (1997)

1996 - Whenever gaps (<5 km) in the GPS data occurred they were infilled with data generated from the doppler navigation system. Gaps in the GPS data greater than ten kilometres were reflown.

1997 - Whenever gaps (<3 km) in the GPS data occurred they were infilled with a linear interpolation over the gap

APPENDIX M

Geophysical Maps

Name	Type	Contour Interval / Vertical Scale		Reference Number
1:250 000 scale				
Goulburn	TMI Contours	10	nT22-1/I55-12/1	
"	Dose Rate Contours	5	nG/hr	22-1/I55-12/18
"	DE Contours	10	m	22-1/I55-12/19
1:100 000 scale				
Boorowa	TMI Contours	5	nT22-2/I55-12/1-1	
"	Dose Rate Contours	2	nG/hr	22-2/I55-12/18-1
"	Flight Path			22-2/I55-12/3-1
"	TMI Profiles	AGC	nT/cm	22-2/I55-12/4-1
Crookwell	TMI Contours	5	nT22-2/I55-12/1-2	
"	Dose Rate Contours	2	nG/hr	22-2/I55-12/18-2
"	Flight Path			22-2/I55-12/3-2
"	TMI Profiles	AGC	nT/cm	22-2/I55-12/4-2
Taralga	TMI Contours	5	nT22-2/I55-12/1-3	
"	Dose Rate Contours	2	nG/hr	22-2/I55-12/18-3
"	Flight Path			22-2/I55-12/3-3
"	TMI Profiles	AGC	nT/cm	22-2/I55-12/4-3
Yass	TMI Contours	5	nT22-2/I55-12/1-4	
"	Dose Rate Contours	2	nG/hr	22-2/I55-12/18-4
"	Flight Path			22-2/I55-12/3-4
"	TMI Profiles	AGC	nT/cm	22-2/I55-12/4-4
Gunning	TMI Contours	5	nT22-2/I55-12/1-5	
"	Dose Rate Contours	2	nG/hr	22-2/I55-12/18-5
"	Flight Path			22-2/I55-12/3-5
"	TMI Profiles	AGC	nT/cm	22-2/I55-12/4-5
Goulburn	TMI Contours	5	nT22-2/I55-12/1-6	
"	Dose Rate Contours	2	nG/hr	22-2/I55-12/18-6
"	Flight Path			22-2/I55-12/3-6
"	TMI Profiles	AGC	nT/cm	22-2/I55-12/4-6

APPENDIX N-1

AGSO ARCHIVE DATA, GRID AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

CONTENTS

APPENDIX N-2

AGSO ARCHIVE DATA, GRID AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

1. THE AGSO SEQUENTIAL FILE STRUCTURE

1.1 INTRODUCTION

This appendix describes the general sequential file structure used by AGSO to store airborne geophysical data.

1.2 GENERAL FILE STRUCTURE

The information pertaining to each traverse (line or tie) is held on the file as a separate entity called a segment. Segments are separated from each other by industry standard EOF records. The end of the file is indicated by two or more consecutive EOF records. Each segment consists of two types of records. Both types are 5120 characters long.

1. Segment Directory Record (SDR) : the first record on each segment. It defines the data content of the segment.
2. Data Records (DAR's) : hold the measured data values. The general structure is shown in Figure 1.

1.3 CHANNELS AND SAMPLES

Data are recorded at regular intervals in time along a traverse. The data recorded at one instant of time are held as any ordered set or sub-set. Each set is held logically distinct and referred to as a channel. The data records in a segment hold all the information for one channel in the form of a data chain, then all the data for the next channel and so on for as many channels as the segment holds.

Each channel is uniquely defined by a channel number and an edition number. The measurement(s) taken for a channel at a given time is called a sample. Samples are held within each channel in increasing order of fiducial (time).

In defining channels the channel number can be used to define the sample format and the edition type of the data. For example, within AGSO, samples with format (longitude, latitude, value, value....) have a channel number of 4 with edition 2 for magnetics and edition 3 for radiometrics.

1.4 SEGMENT DIRECTORY RECORD (SDR)

Lines and ties are uniquely identified as follows :

1. Project number: a unique number to identify the survey.

2. Group number : a unique number within a survey for each flight made. That is, several lines may be recorded on one flight (group). AGSO convention is for group numbers to lie between 001 and 999 inclusive.

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3. Segment numbers : a unique number within a survey for a line or tie. AGSO convention is for ordinary line numbers to lie bewteen 1000 and 9999 inclusive and tie line numbers between 100 and 999 inclusive.

The segment directory record identifies the data segment at Project, Group and Segment level and defines the data channels, their structure and the location of their data chains in the segment. Each SDR consists of one or more 10 word blocks. The first , the Segment Identification Block (SIB), identifies the segment and gives the number of data channels held in the segment.

For this survey the number of data channels is ten as mentioned in the introduction. Subsequent blocks, one for each data channel, define the data channels and their location within the segment. These are called Channel Identification Blocks (CIB's). A typical SDR is shown in Figure 1 and its extact format given in Table 1. All unused words in the SDR are set to zero.

The last word in the record in the past has been used as a check sum and represents the sum of all the other words in the record. The check sum word is no longer used and is set to zero.

The overall record format is 2I9, 509I10, I12.

1.5 DATA RECORD (DAR)

These each contain 512 values. The first two are fiducials giving the fiducial range of the samples contained in the record. The next 508 represent data values, the second last is always zero (to maintain compatability with our random access file format) and the last is a record check sum representing the sum of all other values in the record.

If a record is the last one in a data chain for a given channel all unused values are set to zero, with the next channel commencing at the start of the next data record. The N data records in a segment are numbered from 2 to N+1, the SDR being regarded as record one in a segment, with records for a given channel following each other sequentially. The data record addresses in the channel identification block of the SDR refer to this sequential numbering of the data records. A typical segment is shown in Figure 1 and the exact format of a data record given in Table 2.

The overall format of each data record is : 2I9, 509I10, I12.

1.6 NO DATA VALUE

For a variety of reasons it is sometimes necessary to flag a data value to indicate it is to be ignored. This is achieved by replacing the data word in question by the value 536870912. If a gap exists in a data chain each word of every sample involved must be replaced by 536870912, the so-called missing value. Thus a 1:1 correspondence is maintained between the fiducials encompassed by a data chain and its samples.

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1.7 STANDARD DATA CHANNELS

The standard AGSO data channels are :
channel 4 edition 1 (processed navigation)
channel 4 edition 2 (processed magnetics)
channel 4 edition 3 (processed spectrometrics)
channel 4 edition 4 (processed digital elevation model)
channel 5 edition 1 (doppler)
channel 6 edition 1 (raw spectrometrics)
channel 8 edition 1 (raw magnetics)
channel 14 edition 1 (pressure,temperature,cosmic data)
channel 16 edition 1 (raw navigation)

C4 E1 - Navigation
Channel number = 4
Edition number = 1
Sample size = 2 words
word 1 = Longitude in degrees * 1 000 000
word 2 = Latitude in degrees * 1 000 000

C4 E2 - Corrected Total Magnetic Intensity
Channel number = 4
Edition number = 2
Sample size = 4 words
word 1 and word 2 as for C4 E1
word 3 = final (non micro-levelled) TMI (nT) * 1000
word 4 = final micro-levelled TMI (nT) *1000

C4 E3 - Corrected Gamma-ray Spectrometer Data
Channel number = 4
Edition number = 3
Sample size = 7 words
word 1 and word 2 as for C4 E1
word 3 = Mean Dose Rate (nG/hr) * 1000
word 4 = final Potassium (%K) * 1000
word 5 = final Uranium (ppm eU) * 1000
word 6 = final Thorium (ppm eTh) * 1000
word 7 = Altitude in metres above ground level * 1000

C4 E4 - Corrected Digital Elevation Model Data
Channel number = 4
Edition number = 2
Sample size = 4 words
word 1 and word 2 as for C4 E1
word 3 = final Aircraft Elevation (metres above sea level) * 1000
word 4 = final Terrain Elevation (metres above sea level) * 1000

C5 E1 - Doppler navigation data

Channel number = 5
Edition number = 1
Sample size = 2 words
word 1 = doppler along track (km)
word 2 = doppler across track (m)

C6 E1 - Raw spectrometer data.
Channel number = 6
Edition number = 1
Sample size = 5 words
word 1 = Total count (counts/sec) * 1000
word 2 = Potassium (counts/sec) * 1000
word 3 = Uranium (counts/sec) * 1000
word 4 = Thorium (counts/sec) * 1000
word 5 = Altitude in metres above ground level

C8 E1 - Raw Magnetics
Channel number = 8
Edition number = 1
Sample size = 1 word
word 1 = TMI * 1000

C14 E1 - Pressure and Temperature
Channel number = 14
Edition number = 1
Sample size = 7 words
word 1 = pressure in millibars * 10
word 2 = temperature in degrees celsius * 10
word 3 - 6 = no longer used
word 7 = cosmic channel (counts) * 1000

C16 E1 - Raw GPS data
Channel number = 16
Edition number = 1
Sample size = 4 words
word 1 = Longitude in degrees * 1 000 000
word 2 = Latitude in degrees * 1 000 000
word 3 = GPS time in seconds * 1000.
GPS time is recorded in seconds from midnight the previous Sunday
word 4 = Lag time. Time difference between time when a position is calculated and time until the next fiducial is generated by the data acquisition system. (hundredths of a second)
word 5 = GPS delay

2. PHYSICAL FORMAT FOR MAGNETIC TAPES

2.1 GENERAL

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Each magnetic tape (MT) consists of a sequence of segments, each segment consisting of one or more physical records. Segments are to be separated by one EOF markers. The end of all information on a tape must be flagged by two or more consecutive EOF markers. Industry standard EOF records apply. Records are to be fixed length and each block is to contain one record.

2.2 PHYSICAL PARAMETERS OF TAPES

a. Tapes are 12.7 mm (0.5 inch) wide, 9 track industry standard magnetic tapes.
b. Each tape has an external label identifying the airborne survey, character code, recording density, date tape written and the reel number in the set.

2.3 TAPE STRUCTURE

a. 9 track
b. Written in ASCII
c. Recording density of 6250 bpi
d. International Standards Organisation end-of-block markers (EOB)
e. International Standards Organisation end-of-file markers (EOF)
f. No multi-tape files
g. Multi-file tapes can be expected. Files will not span tapes.
h. Last file on each tape shall end with at least two EOF's.

2.4 PHYSICAL RECORDS AND BLOCKS

a. Fixed length records of 5120 characters
b. One record per block

3. GRID FILE FORMAT

3.1 HEADER RECORD

The first record on the file defines the content of the grid, including:

a. Origin in latitude and longitude.
b. Grid cell size.
c. Number of rows and columns in the grid.
d. Storage mode, i.e. whether the data is stored row by row or column by column. In general the data is stored by row.
e. The exact header record format is in Table 3.

3.2 DATA RECORDS

Each data record contains 320 values in E16.10 format. No location data is held in the data records - the location of a grid point is determined by its sequence within the file. The data for the grid may be sequenced in row or column order (i.e. row by row or column by column respectively). Each row or column is written on consecutive records and begins at the start of a new record. If the rows/columns do not contain a multiple of 320 values the last record for each row/column is padded with zeros. Any point in the grid which is undefined is set to -9999.0.

In ROW mode , rows are sequenced from north to south and within each row values are ordered from west to east.

In COLUMN mode, columns are sequenced from west to east and within each column values are ordered from north to south.

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TABLE 1

SEGMENT DIRECTORY RECORD FORMAT

1. SEGMENT IDENTIFICATION BLOCK

WORD	CONTENT AND USE	FORMAT
1	PROJECT IDENTIFICATION	I9
2	GROUP IDENTIFIACTION	I9
3	SEGMENT IDENTIFICATION	I10
4	NUMBER OF CHANNELS ON SEGMENT	I10
5	DATE CODE - YYMMDD	I10
6	FIDUCIAL FACTOR - (fiducial size in seconds)	I10
7	TIME OF DAY AT FIDUCIAL ZERO IN SECONDS	I10
8	BEARING IN DEGREES (0-359) MEASURED EAST OF NORTH	I10
9	ALTITUDE IN METRES ABOVE SEA LEVEL	I10
10	GROUND CLEARANCE IN METRES	I10

2. CHANNEL IDENTIFICATION BLOCK (for the Nth channel)

WORD	CONTENT AND USE	FORMAT
1	CHANNEL CODE	I10
2	EDITION NUMBERS	I10
3	FIDUCIAL INTERVAL BETWEEN SAMPLES	I10
4	NUMBER OF DATA VALUES (WORDS) PER SAMPLE	I10
5	ADDRESS OF FIRST DATA RECORD FOR CHANNEL	I10
6	ADDRESS OF LAST SAMPLE IN DATA CHAIN	I10
7	FIDUCIAL OF FIRST SAMPLE IN DATA CHAIN	I10
8	FIDUCIAL OF LAST SAMPLE IN DATA CHAIN	I10
9	UNUSED - SET TO ZERO	I10
10	UNUSED - SET TO ZERO	I10

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TABLE 2

DATA RECORD FORMAT

WORD	CONTENT AND USE	FORMAT
1	FIDUCIAL AT FIRST DATA SAMPLE IN RECORD	I9
2	FIDUCIAL AT LAST DATA SAMPLE IN RECORD	I9
3	FIRST WORD OF FIRST SAMPLE	I10
4	SECOND WORD OF FIRST SAMPLE	I10
	FIRST WORD OF SECOND SAMPLE	I10
	SECOND WORD OF SECOND SAMPLE	I10
	ETC	
511	ALWAYS UNUSED - SET TO ZERO	I10
512	ALWAYS UNUSED - SET TO ZERO	I12

NOTE:

1. A data sample can be of any length greater than zero.
2. Each record contains an integral number of samples. This may lead to several unused words at the end of the record which are set to zero.

   i.e. If a sample is 7 words long 72 samples will fit in a data record and words 507-510 will be set to zero.

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TABLE 3

GRID HEADER RECORD FORMAT

CHARACTER POSITION	FIELD LENGTH	FORTRAN FORMAT	CONTENT
1-60	60	6A10	Grid Identification
61-170	10	11A10	Facts defining data acquisition/processing
171-180	10	A10	x,y units defining grid, Usually degrees.
181-192	12	E12.6	x origin of surface. Bottom left hand corner.
193-204	12	E12.6	y origin of surface. Bottom left hand corner.
205-214	10	A10	Type of z data in grid (e.g. TMI).
215-216	2	A2	Blanks.
217-228	12	I12	Number of data records per column or row.
229-240	12	E12.6	Grid increment in the x direction
241-252	12	E12.6	Grid increment in the y direction
253-262	10	A10	Time when original surface created (hh.mm.ss).
263-286	24	2A10,A4	Filter used on original z data.
287-310	12	2E12.6	x,y co-ordinate of the bottom left hand corner of the grid. Same as x,y origin.
311-320	10	A10	Date of creation of surface (dd/mm/yy).
321-344	24	2A10,A4	Blanks.
345-368	12	2E12.6	x,y co-ordinate of top right hand corner of grid. NOTE: these values are too large by one grid increment for tapes created prior to 01/06/85.
369-373	5	I5	Number of rows in the grid.
374-378	5	I5	Number of columns in the grid.
379-382	4	A4	Blanks.
383-388	6	A6	Defines if the grid is stored in column mode (COLUMN) or row mode (ROW).
389-5120			Blank filled.