ACQUISITION and PROCESSING REPORT

of a
HIGH RESOLUTION AEROMAGNETIC SURVEY

over
NORTHERN BRITISH COLUMBIA

for
The GEOPHYSICS DIVISION of
NATURAL RESOURCES CANADA
PROJECT NUMBER 930002
PHASE II 1995-1997

Job Nº 182
April 1997
Ottawa, Ontario
B. Schacht, P. Geoph.

geoterrex

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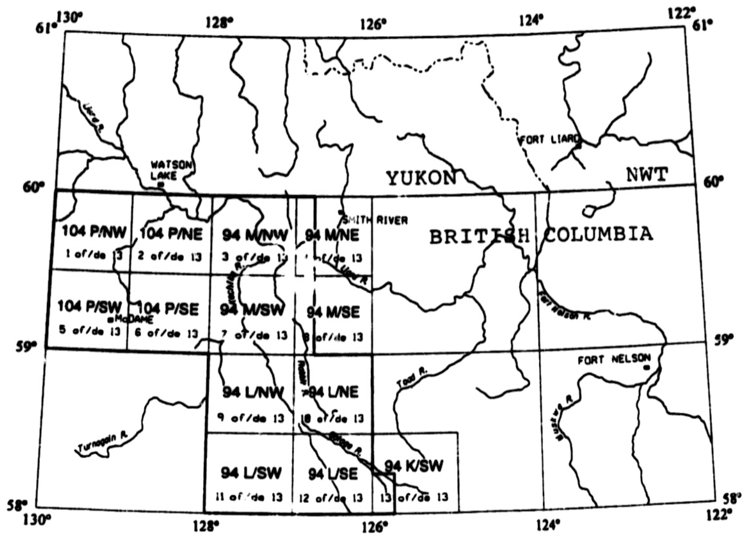
A Equipment Log Book
B Digital Archive Format

SURVEY LOCATION



NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND GEOPHYSICAL INDEX FOR GEOLOGICAL SURVEY OF CANADA MAPS

FIGURE 1

1. INTRODUCTION

From July 26, 1995 to February 29, 1996, a total of 51,244 line kilometres of high sensitivity aeromagnetic data were flown over northern British Columbia by GEOTERREX (see figure 1).

The objective of the survey was to provide regional mapping to define basement structures and, within the limitations of its 0.8 x 5 km grid, magnetic sources within the overlying sediments. These areas were flown under contract to the Geological Survey of Canada. The data will be included in the National Aeromagnetic Data Base.

2. SURVEY OPERATIONS

Location of the Survey Area

The area is bound by the following co-ordinates (see figure 1):

58°00'00"N	128°00'00"W
59°00'00"N	128°00'00"W
59°00'00"N	130°00'00"W
60°00'00"N	130°00'00"W
60°00'00"N	126°45'00"W
59°00'00"N	126°45'00"W
59°00'00"N	126°00'00"W
58°15'00"N	126°00'00"W
58°15'00"N	125°45'00"W
58°00'00"N	125°45'00"W

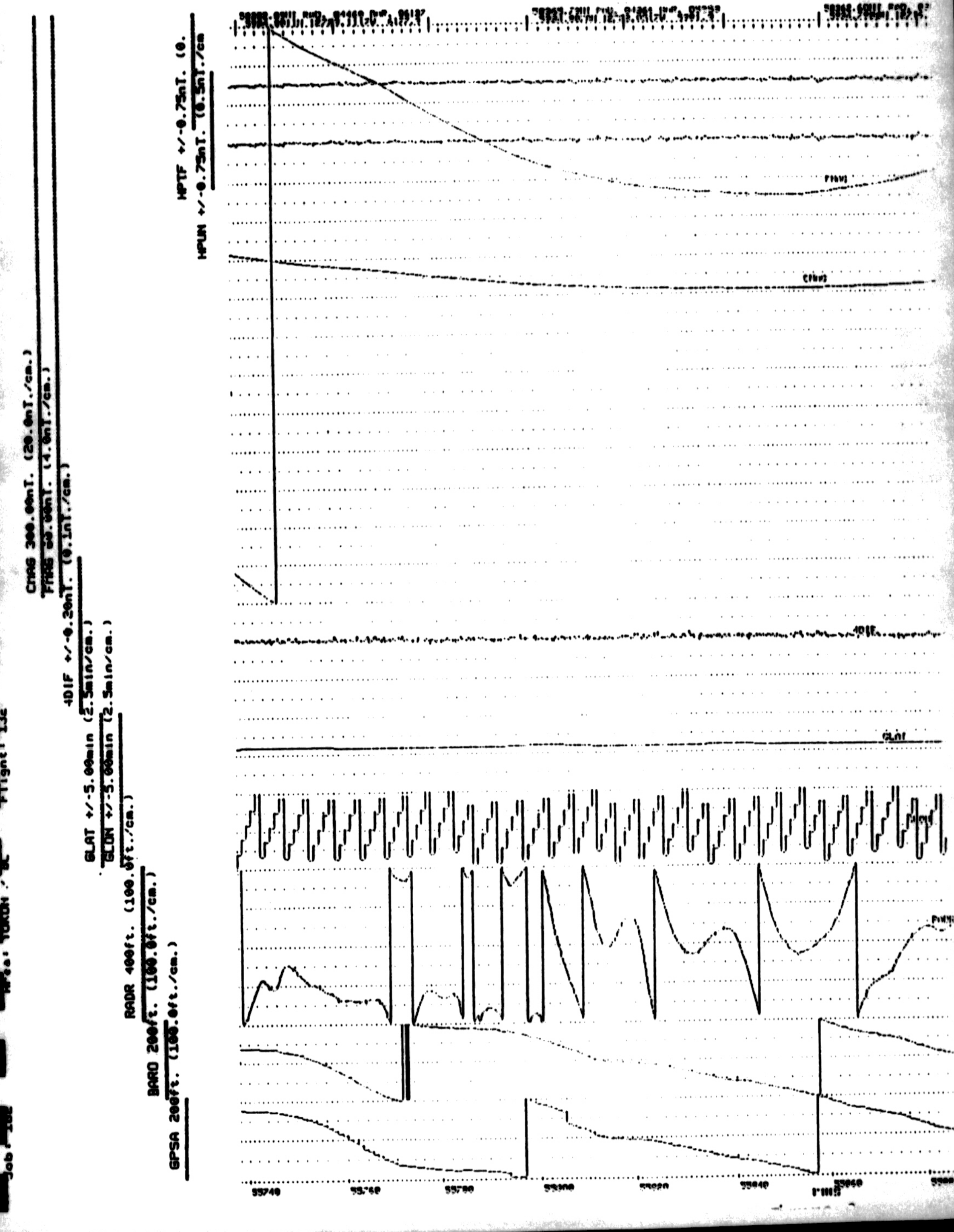
The base of operation was Watson Lake, Yukon Territory.

Aircraft and Geophysical On-Board Equipment

Aircraft	Titan 404
Operator	Geoterrex
Registration	C-GMEL
Survey Speed	165 knots/190 mph/85 m/sec.
Magnetometer	Scintrex single cell cesium vapour, stinger mounted, sensitivity = 0.005 nT[1], sampling rate = 0.1 sec. (reduced to 0.2 sec, about 16 m, for data processing) ambient range 20,000 to 100,000 nT. The general noise envelope was kept below 0.1 nT. Compensation was by Sonotek, 27 term.
Digital Acquisition	Geoterrex GEODAS.
Analog	A sample analog is shown in figure 2, reduced by 21% to fit on the page. The high-pass filtered traces emphasized anomalies up to a 4 second period from the uncompensated (HPUN) and compensated (HPTF) magnetic data, with a 3.9 second lag. The fourth difference trace has been divided by 16.

[1] One gamma is equivalent to the S.I. unit nanotesla (nT).

AIRCRAFT ANALOGUE RECORD



	The absolute values of mag.(nT), radar, GPS and barometric altimeters (feet), and GPS latitude and longitude (degrees and minutes) are printed at the top of the page every 60 seconds.
Barometric Altimeter	Rosemount 1241M, sensitivity 2 feet, 0.5 sec. recording interval.
Radar Altimeter	TRT AHV6, accuracy 1%, sensitivity one foot, range 0 to 10,000 feet, 0.5 sec. recording interval.
Camera	Panasonic colour video, model WV- CL 302, with an 8 mm lens giving a 46.2° field of view.
Electronic Navigation	Sercel GPS receiver NR103, 1.2 sec. recording interval, with a resolution of 0.00001 degree and an accuracy of 10 m, operating with OMNISTAR real-time correction.
	Vertical guidance to a predetermined drape surface was provided by a laptop computer which converts the GPS X-Y's to the desired elevation, checks the actual GPS elevation, and displays any necessary elevation corrections on the screen.

Base Station Equipment - Watson Lake (main) and Fort Nelson (remote)

- A Scintrex single cell split beam cesium vapour magnetometer, mounted in a magnetically quiet area, measuring the total intensity of the earth's magnetic field in units of 0.01 nT at intervals of 1 second, with a noise envelope of 0.05 nT.
- SERCEL NR103 GPS receiver, measuring all GPS channels, for up to 10 satellites, at 6 second intervals. A GPS receiver was not needed at the remote base in Fort Nelson. The satellite time was transferred on a daily basis, by telephone, from the main base.
- Toshiba laptop computer, model T4600.
- Picodas converter, model MEP710 3/10901 GTS 780008.
- Kodak Diconix 150 Plus printer.
- Battery backup in case of power failure.

Field Office Equipment

- TOUCH 486 computer with a Samtron colour monitor.
- Digital personal DEC station 5000/25 with a Digital VRC16 colour monitor.
- OKI Macroline 192 Plus printer.
- Calcomp Design Mate 24" colour plotter, using 2000 steps per inch.
- Panasonic GX4 model AG1950 VCR with an 8" Brule colour monitor for video recovery.
- GMAPS software to process data from field tapes to contours.

- Excalibur 1.3 gigabyte hard drive.
- Maynard 2000 DAT tape drive.

Survey Specifications

Altitude: Smooth drape to within 300 m of the highest peaks. This was computer guided by the Geoterrex AccuDrape system (see electronic navigation, on page 3) which eliminated elevation misclosures at traverse/control-line intersections. The AccuDrape system, which was developed for this job, eliminates the need for elevation blocks in any area where real-time GPS correction is available.

The altitude tolerance was limited to ± 30 m (100 feet).

Traverse Lines: Spacing of 0.8 km, direction E-W.

All traverse lines extended at least 1 km beyond the survey boundaries at survey altitude and two traverse lines were flown outside of the survey area to provide valid information beyond the map boundaries.

Traverse lines were flown parallel to the latitudes, offset from map sheet boundaries.

Tolerances (traverse lines): 1.0 km maximum separation.

Gaps in coverage up to 1.1 km were permitted over a distance up to 5 km and never greater than 1.2 km or less than 0.2 km. Parts of lines reflown to complete a flight line crossed control lines at either end and crossed the original survey line at a low angle at a point where the data is acceptable.

No navigation gaps exist on the final products.

Control lines: Spacing of 5 km, direction N-S.

Control lines extended at least 1 km beyond the survey boundary. These flights were initiated during optimum diurnal conditions. The control line data was levelled and used in the gridding process. Control lines were flown parallel to the longitudes, offset from map sheet boundaries.

Diurnal variation: 3 nT deviation from a long chord equivalent to the average control line spacing: about 62 seconds.

Lines or portions of lines flown during periods of greater diurnal activity were reflown. These reflights began and ended by crossing control lines.

Prior to commencing the survey, Geoterrex conducted an examination of records of the government magnetic observatory in Yellowknife, N.W.T. These records indicated that a 3 nT specification might require an onerous amount of reflights and/or downtime for diurnal activity. Thus a 6 nT specification was tentatively adopted by Geoterrex, with the provision that diurnal reflights/downtime be reviewed before demobilization. The resultant broadening of the noise envelope was infrequent; (the diurnal activity was not as bad as expected) and it was counterbalanced by exceptional measures taken during data processing to remove diurnal events well below the 3 nT specification.

Tests and Calibrations

Figure of Merit

The Figure of Merit (FOM) is a series of pitches (± 5°), rolls (± 10°), and yaws (± 5°) which induce noise in the magnetometer resulting from aircraft manoeuvres (due to the magnetic fields generated by the aircraft itself). This test shows how well the installation is compensated. The results of a test flown in Watson Lake on December 11, 1995 are illustrated in figures 3-6. The F.O.M. value for this test was 1.64 nT. All F.O.M.'s are tabled below:

July 11, 1995, Ottawa, Ontario

Heading	Manoeuvre	Value	Total
North	Roll	0.18 nT	
	Pitch	0.19 nT	
	Yaw	0.12 nT	0.49
South	Roll	0.17 nT	
	Pitch	0.13 nT	
	Yaw	0.15 nT	0.45
East	Roll	0.17 nT	
	Pitch	0.18 nT	
	Yaw	0.12 nT	0.47
West	Roll	0.07 nT	
	Pitch	0.13 nT	
	Yaw	0.13 nT	0.33

FOM = 1.74 nT

Figure of Merit direction East

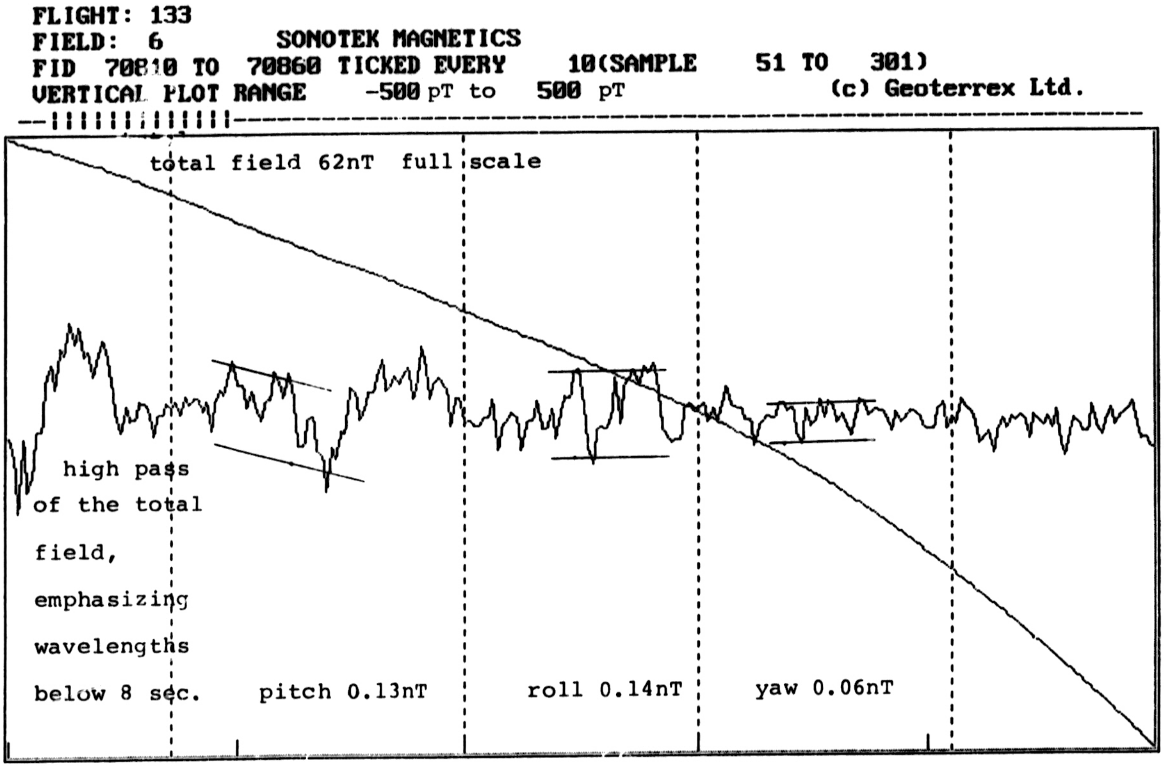


Figure 3

Figure of Merit direction North

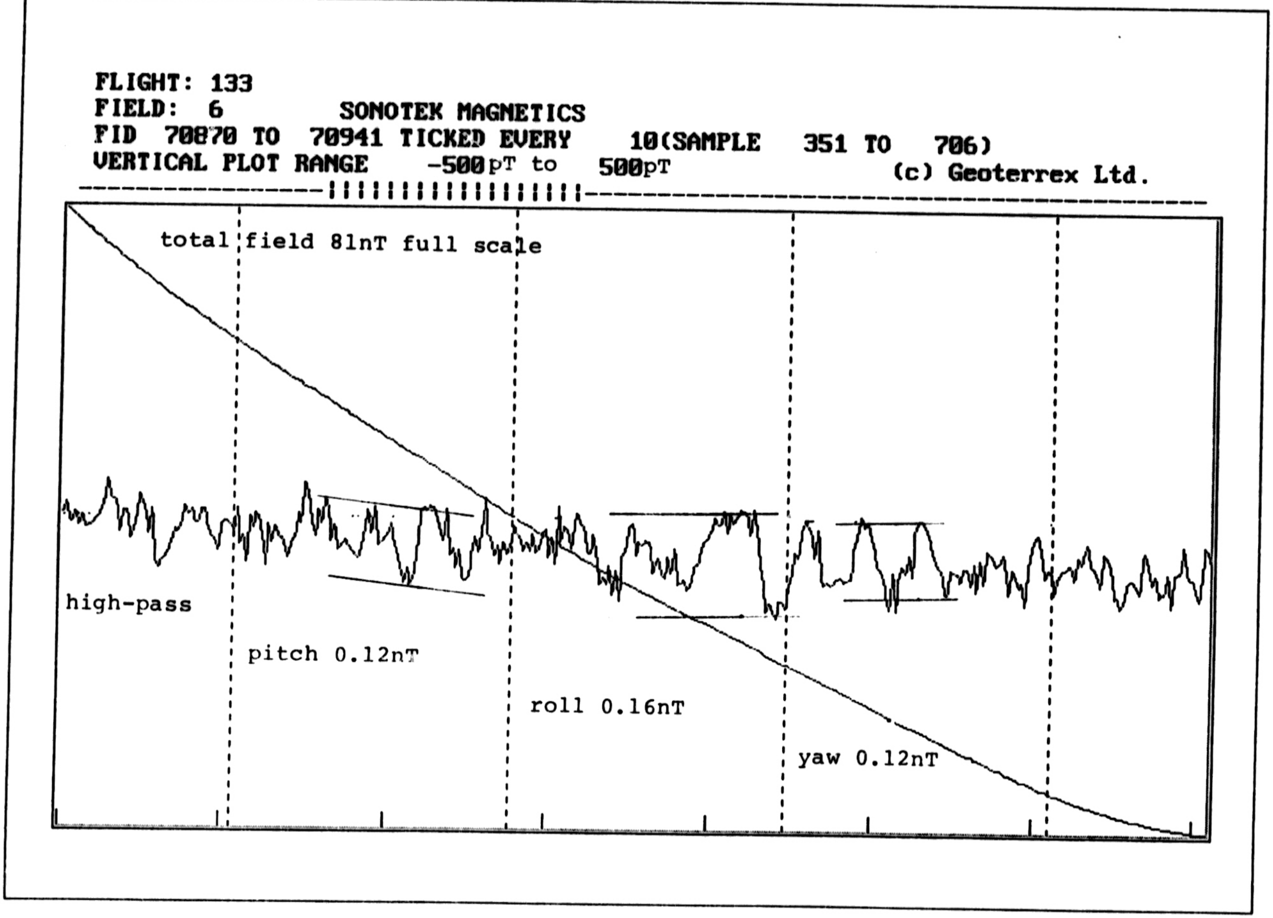


Figure 4

Figure of Merit direction West

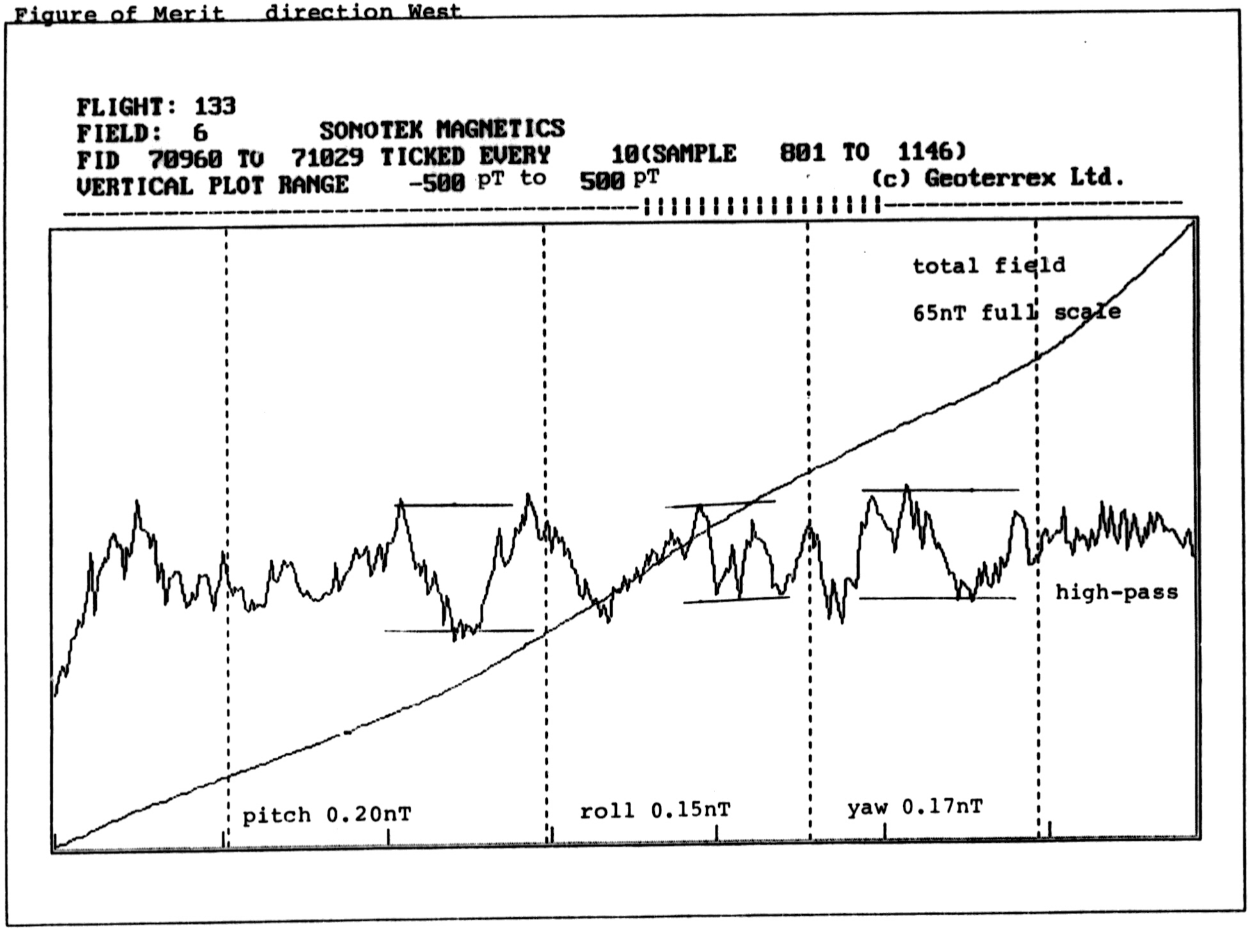


Figure 5

Figure of Merit direction South

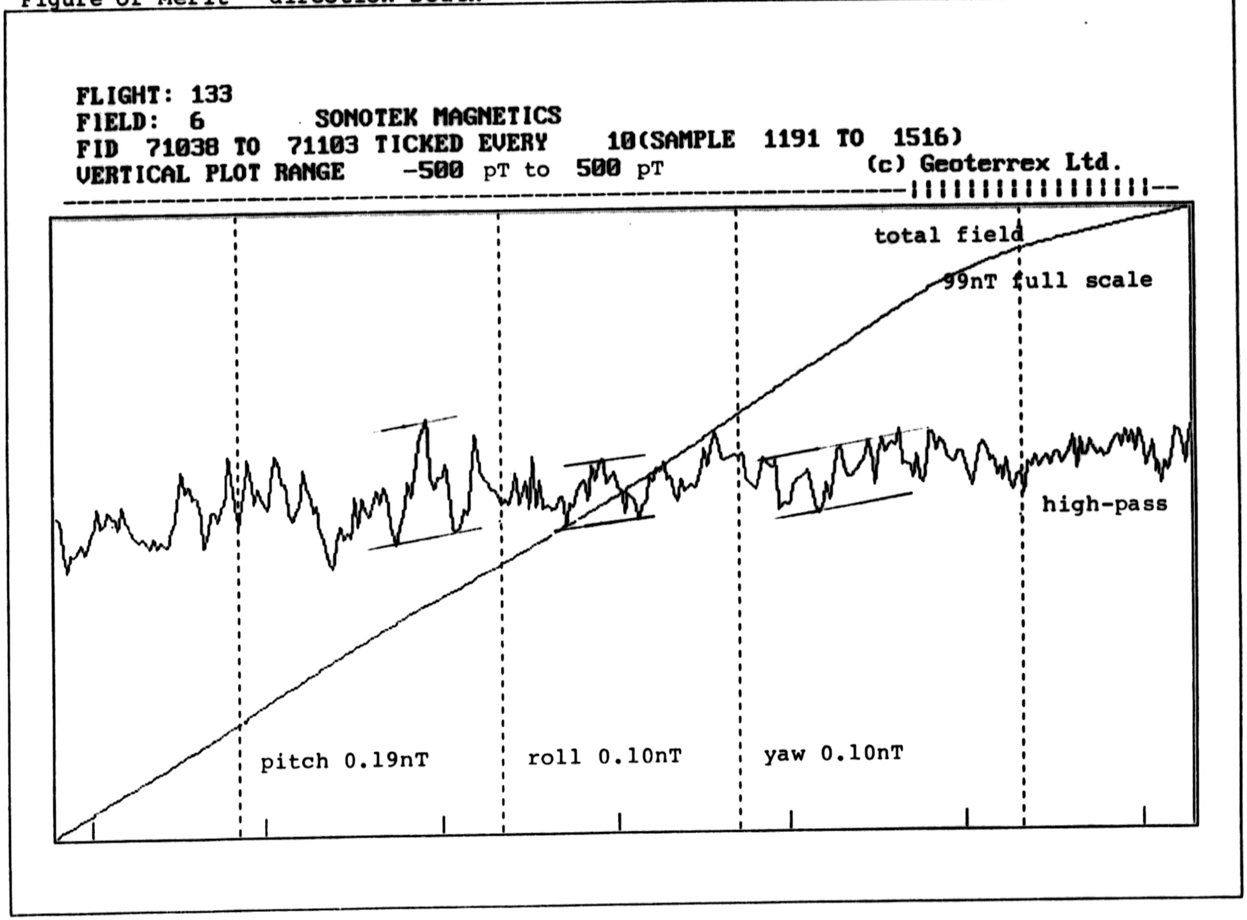


Figure 6

July 26, 1995, Watson Lake, Yukon Territory

Heading	**Manoeuvre**	**Value**	**Total**
West	Roll	0.13 nT	
	Pitch	0.10 nT	
	Yaw	0.20 nT	0.43
South	Roll	0.10 nT	
	Pitch	0.12 nT	
	Yaw	0.14 nT	0.36
East	Roll	0.13 nT	
	Pitch	0.11 nT	
	Yaw	0.14 nT	0.38
North	Roll	0.07 nT	
	Pitch	0.12 nT	
	Yaw	0.20 nT	0.39

FOM = 1.56 nT

August 20, 1995, Watson Lake, Yukon Territory

Heading	**Manoeuvre**	**Value**	**Total**
South	Roll	0.08 nT	
	Pitch	0.13 nT	
	Yaw	0.10 nT	0.31
West	Roll	0.10 nT	
	Pitch	0.10 nT	
	Yaw	0.13 nT	0.33
North	Roll	0.10 nT	
	Pitch	0.16 nT	
	Yaw	0.16 nT	0.42
East	Roll	0.10 nT	
	Pitch	0.14 nT	
	Yaw	0.10 nT	0.34

FOM = 1.40 nT

September 13, 1995, Watson Lake, Yukon Territory

FOM = 0.78 nT

October 11, 1995, Watson Lake, Yukon Territory

Heading	Manoeuvre	Value	Total
South	Roll	0.13 nT	
	Pitch	0.17 nT	
	Yaw	0.11 nT	0.41
West	Roll	0.09 nT	
	Pitch	0.14 nT	
	Yaw	0.14 nT	0.37
North	Roll	0.09 nT	
	Pitch	0.15 nT	
	Yaw	0.13 nT	0.37
East	Roll	0.10 nT	
	Pitch	0.17 nT	
	Yaw	0.15 nT	0.42

FOM = 1.57 nT

October 20, 1995, Watson Lake, Yukon Territory

Heading	Manoeuvre	Value	Total
South	Roll	0.13 nT	
	Pitch	0.14 nT	
	Yaw	0.15 nT	0.42
West	Roll	0.22 nT	
	Pitch	0.17 nT	
	Yaw	0.14 nT	0.53
North	Roll	0.16 nT	
	Pitch	0.16 nT	
	Yaw	0.21 nT	0.53

East	Roll	0.10 nT	
	Pitch	0.19 nT	
	Yaw	0.14 nT	0.43

FOM = 1.91 nT

November 18, 1995, Watson Lake, Yukon Territory

Heading	**Manoeuvre**	**Value**	**Total**
South	Roll	0.05 nT	
	Pitch	0.05 nT	
	Yaw	0.08 nT	0.18
West	Roll	0.08 nT	
	Pitch	0.15 nT	
	Yaw	0.13 nT	0.36
North	Roll	0.10 nT	
	Pitch	0.15 nT	
	Yaw	0.12 nT	0.37
East	Roll	0.10 nT	
	Pitch	0.17 nT	
	Yaw	0.06 nT	0.33

FOM = 1.24 nT

December 11, 1995, Watson Lake, Yukon Territory

Heading	**Manoeuvre**	**Value**	**Total**
South	Roll	0.10 nT	
	Pitch	0.19 nT	
	Yaw	0.10 nT	0.39
West	Roll	0.15 nT	
	Pitch	0.20 nT	
	Yaw	0.17 nT	0.52
North	Roll	0.16 nT	
	Pitch	0.12 nT	
	Yaw	0.12 nT	0.40

East	Roll	0.14 nT	
	Pitch	0.13 nT	
	Yaw	0.06 nT	0.33

FOM = 1.64 nT

February 14, 1996, Watson Lake, Yukon Territory

Heading	**Manoeuvre**	**Value**	**Total**
South	Roll	0.10 nT	
	Pitch	0.10 nT	
	Yaw	0.10 nT	0.30
West	Roll	0.08 nT	
	Pitch	0.14 nT	
	Yaw	0.12 nT	0.34
North	Roll	0.07 nT	
	Pitch	0.11 nT	
	Yaw	0.17 nT	0.35
East	Roll	0.10 nT	
	Pitch	0.12 nT	
	Yaw	0.14 nT	0.36

FOM = 1.35 nT

March 4, 1996, Watson Lake, Yukon Territory

Heading	**Manoeuvre**	**Value**	**Total**
South	Roll	0.15 nT	
	Pitch	0.14 nT	
	Yaw	0.08 nT	0.37
West	Roll	0.11 nT	
	Pitch	0.14 nT	
	Yaw	0.17 nT	0.42
North	Roll	0.10 nT	
	Pitch	0.12 nT	
	Yaw	0.21 nT	0.43

East	Roll	0.10 nT	
	Pitch	0.12 nT	
	Yaw	0.12 nT	0.34

FOM = 1.56 nT

Magnetic Cloverleaf/Calibration

These tests compared the absolute value of the Geoterrex aircraft magnetometer in the four cardinal directions, with government reference magnetometers at Bourget, Ontario and Meanook, Alberta. The difference in the total magnetic field, between these observatories and a point 1000 feet above nearby crossroads, has been determined.

The results of the tests performed pre- and post-survey are tabled below:

July 11, 1995, Bourget crossroads vs. Blackburn observatory

Flight direction	Altitude (ft. above ground)	Total Field Difference (nT) (a positive means Geoterrex values are higher)
North	1000	-1.05
South	1000	-0.31
East	1000	-1.31
West	1000	-1.21
North	1000	-1.06
South	1000	-0.42
East	1000	-0.71
West	1000	-0.51
		Average = -0.82

March 13, 1996, Meanook crossroads vs. Meanook Observatory

North	1000	-15.84
South	1000	-9.43
East	1000	-4.15
West	1000	-4.29
North	1000	-2.75
South	1000	+0.72
East	1000	-7.03
West	1000	-6.69
		Average = -6.18

Lag Test

The camera on-board the aircraft records its position, A, relative to the ground at time t_0. In fact the sensor will arrive over A at time t_1 greater than t_0. Furthermore, because of electronic delays, the reading performed at time t_1 will be recorded on the magnetic tape at time t_2 greater than t_1.

The difference t_2-t_0 represents the lag between the actual aircraft position and the position of the corresponding reading on the magnetic tape. This difference, called a "lag", must be determined at the beginning of the survey and every time a key piece of equipment is changed in the aircraft.

The test was performed by flying the aircraft at 305 m terrain clearance in opposite directions over a well defined magnetic anomaly (illustrated in figures 7 and 8). A lag value of 0.4 seconds was taken into account at the processing stage by shifting the digital mag values back 4 sample intervals with regard to the fiducial field. This was done in the 0.1 second sample intervals.

Altimeter Calibration

Before the survey, the radar altimeter was checked against the barometric altimeter and GPS elevation. The test consisted of flying at 600', 800', 1000', 1600' and 2000' terrain clearance over a flat area of known elevation (Ottawa river, 242' A.S.L.). Results are illustrated in figures 9 to 13.

Throughout the survey, significant discrepancies were noted between the barometric altimeter and the differentially corrected GPS elevation. These discrepancies grew greater and more frequent as the survey extended into the winter months; thus we expected the discrepancies were due to temperature (see figure 14). At the conclusion of the survey, a calibration was made between the barometric altimeter and the GPS altimeter at barometric elevations of 800, 1000, 1250, 1500, 1750 and 2000 metres (see figure 15). To reduce the chance of barometric pressure changes, the test was made immediately after takeoff in the area of the airport. The discrepancies observed in figure 15 are not inconsistent with those predicted in figure 14, considering the surface temperature early that morning was -24°C.

Our recommendation is that all future jobs with potential cold weather acquisition be altitude controlled by real-time corrected GPS (or radar where appropriate). The GPS elevation is also free from the effect of air-pressure changes, which can cause barometric altitude errors of 100 metres or more.

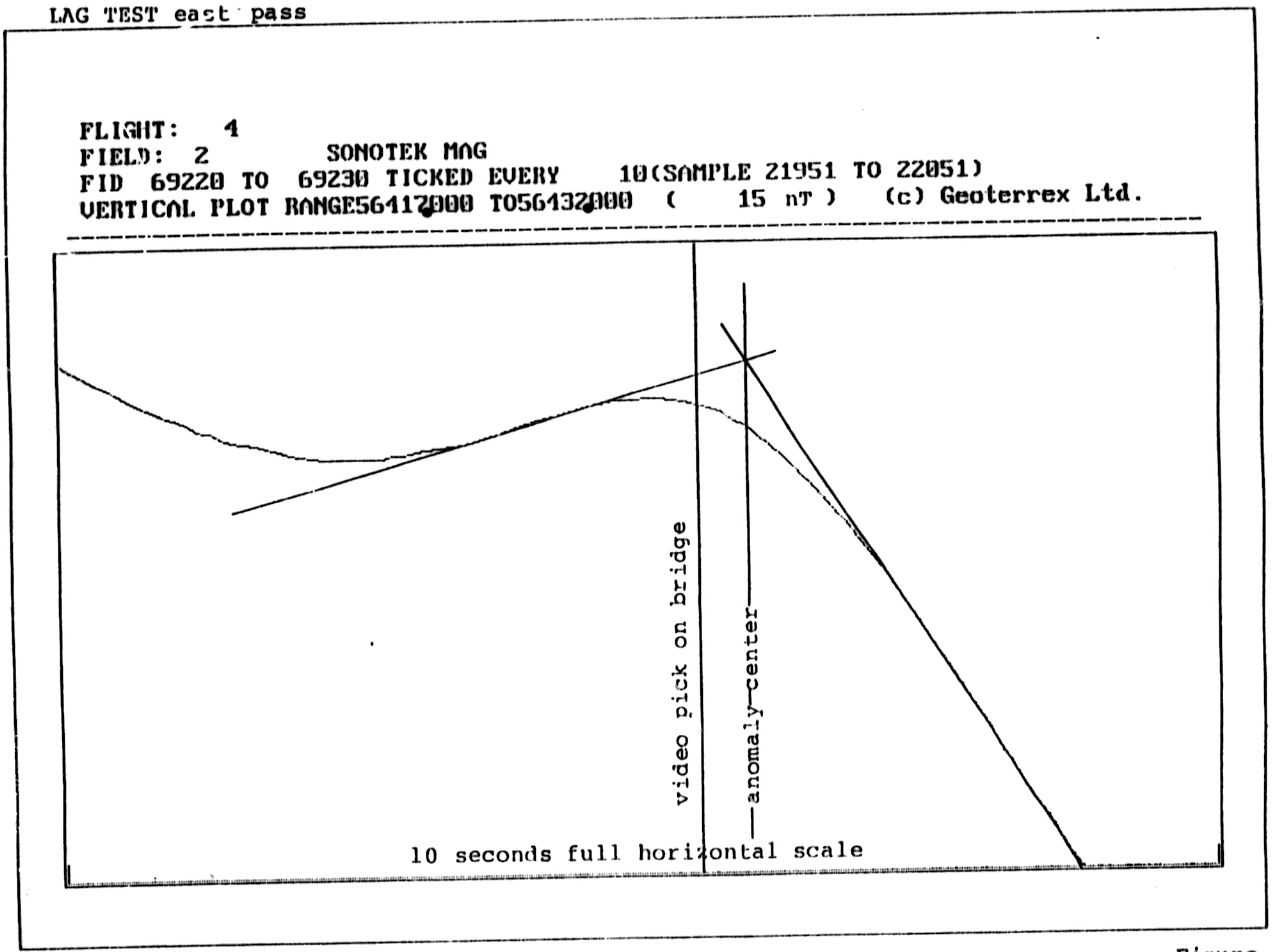

LAG TEST east pass
FLIGHT: 4
FIELD: 2 SONOTEK MAG
FID 69220 TO 69230 TICKED EVERY 10(SAMPLE 21951 TO 22051)
VERTICAL PLOT RANGE56417000 TO56432000 (15 nT) (c) Geoterrex Ltd.
video pick on bridge
anomaly center
10 seconds full horizontal scale

Figure 7

LAG TEST west pass

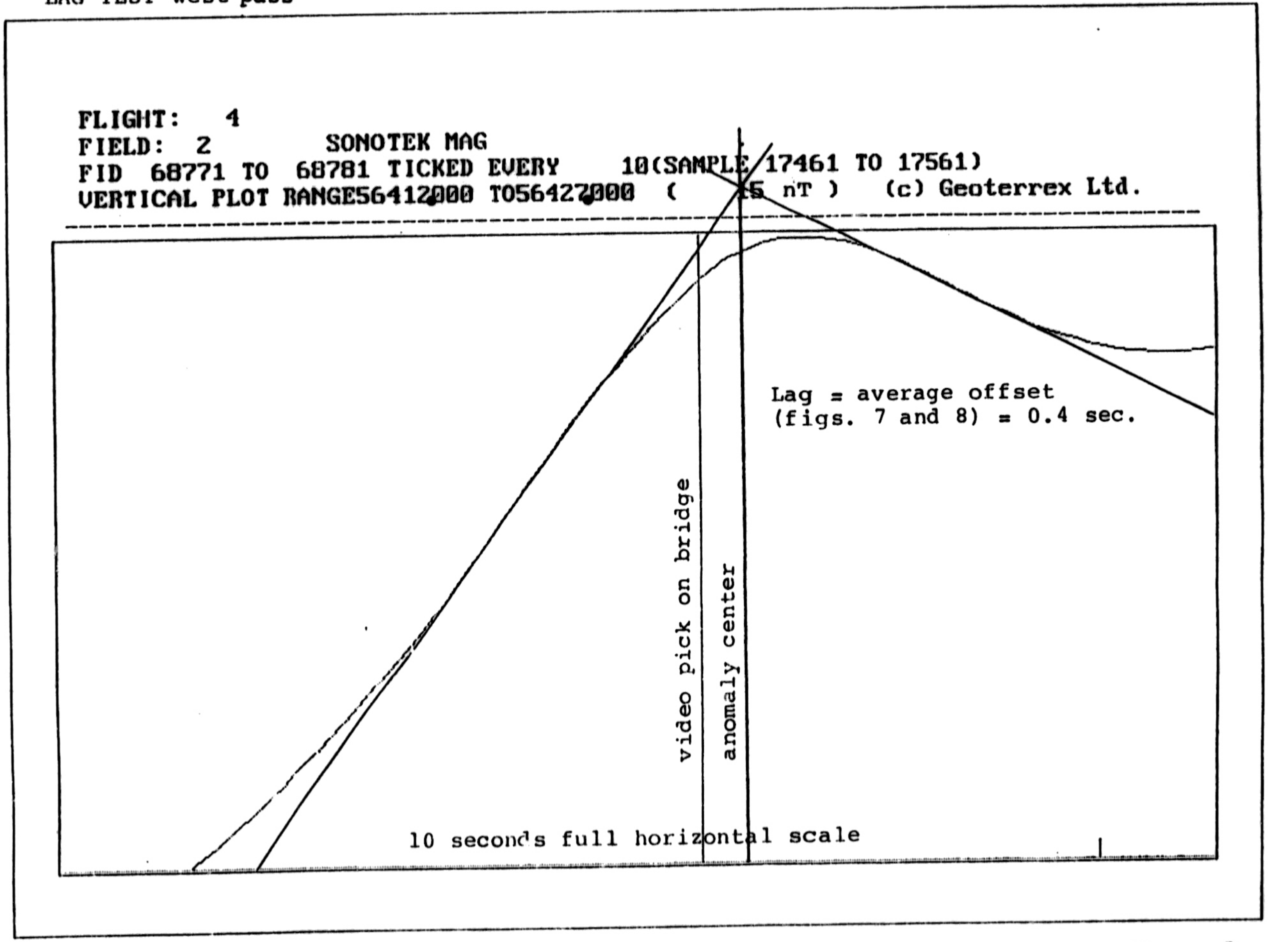


Figure 8

ALTIMETER CALIBRATION (1 Of 5)

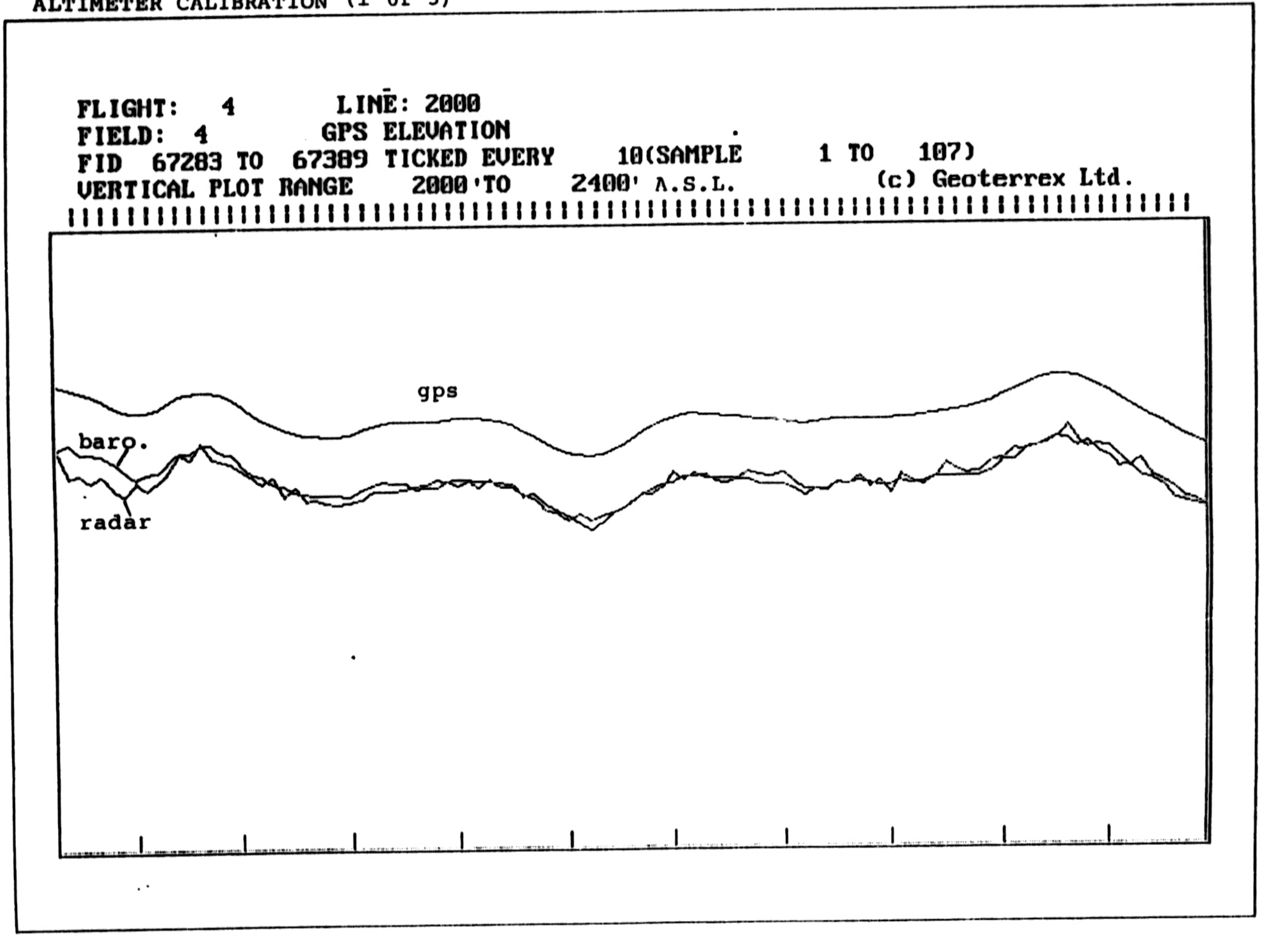


Figure 9

ALTIMETER CALIBRATION (2 of 5)

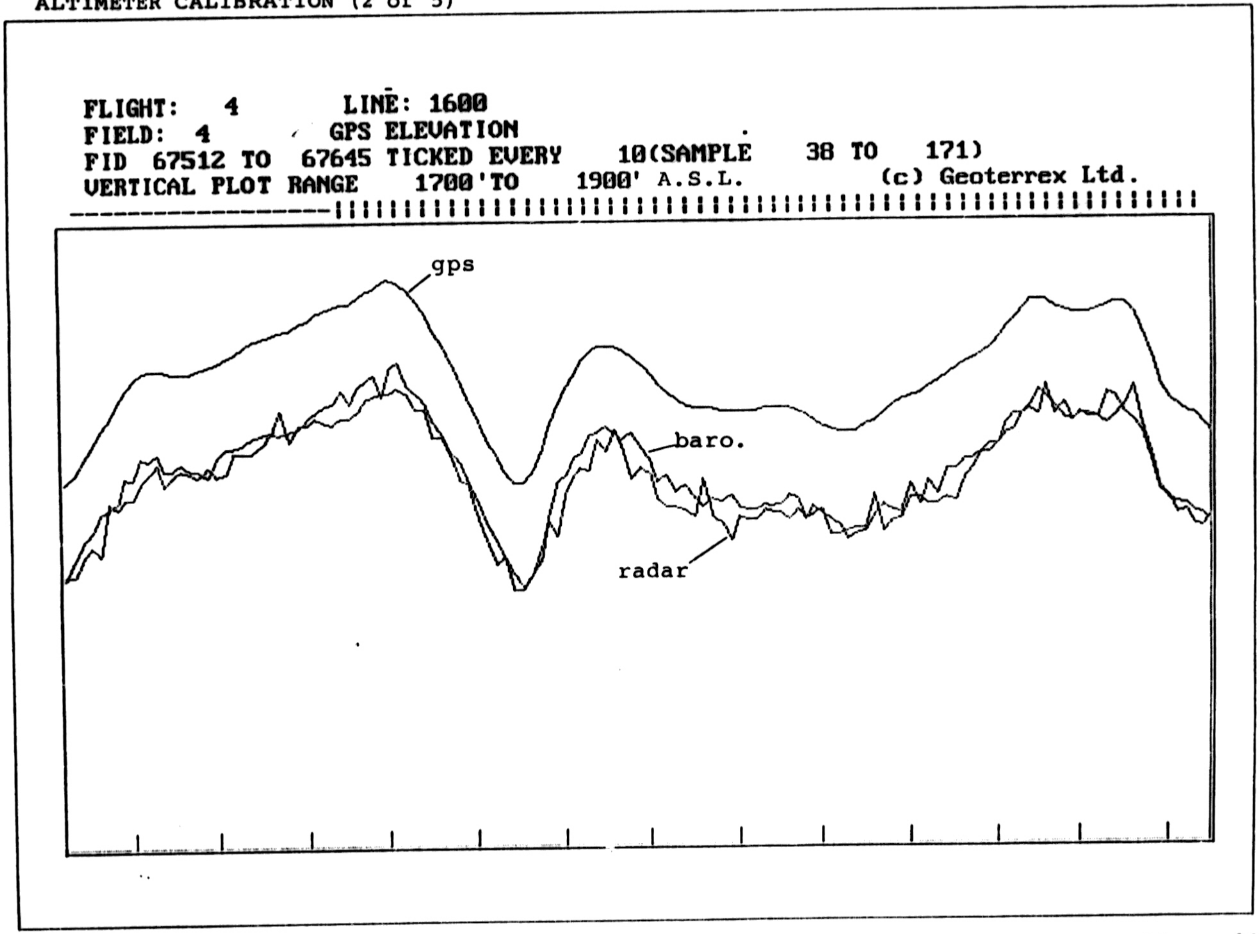


Figure 10

ALTIMETER CALIBRATION (3 Of 5)

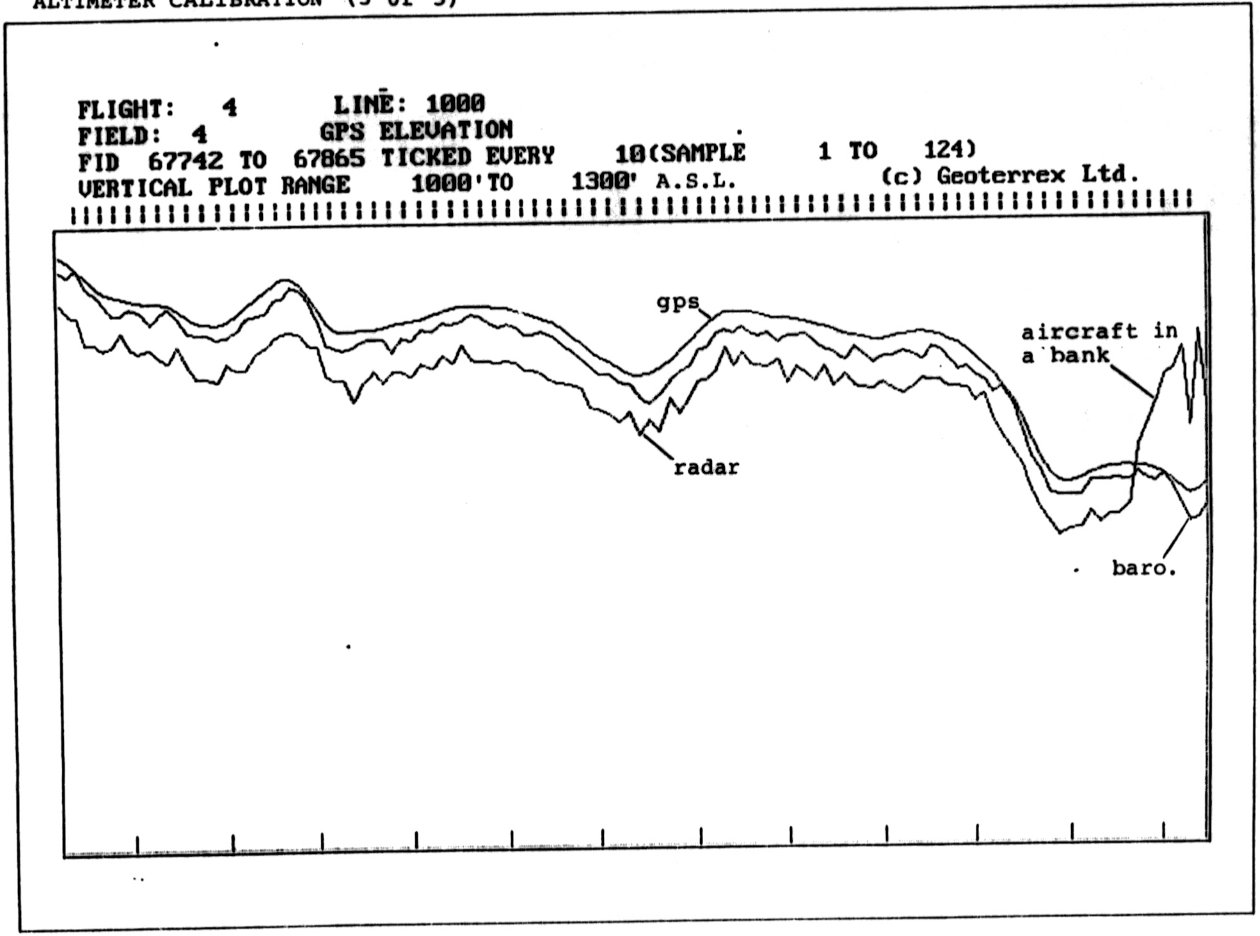


Figure 11

ALTIMETER CALIBRATION (4 of 5)

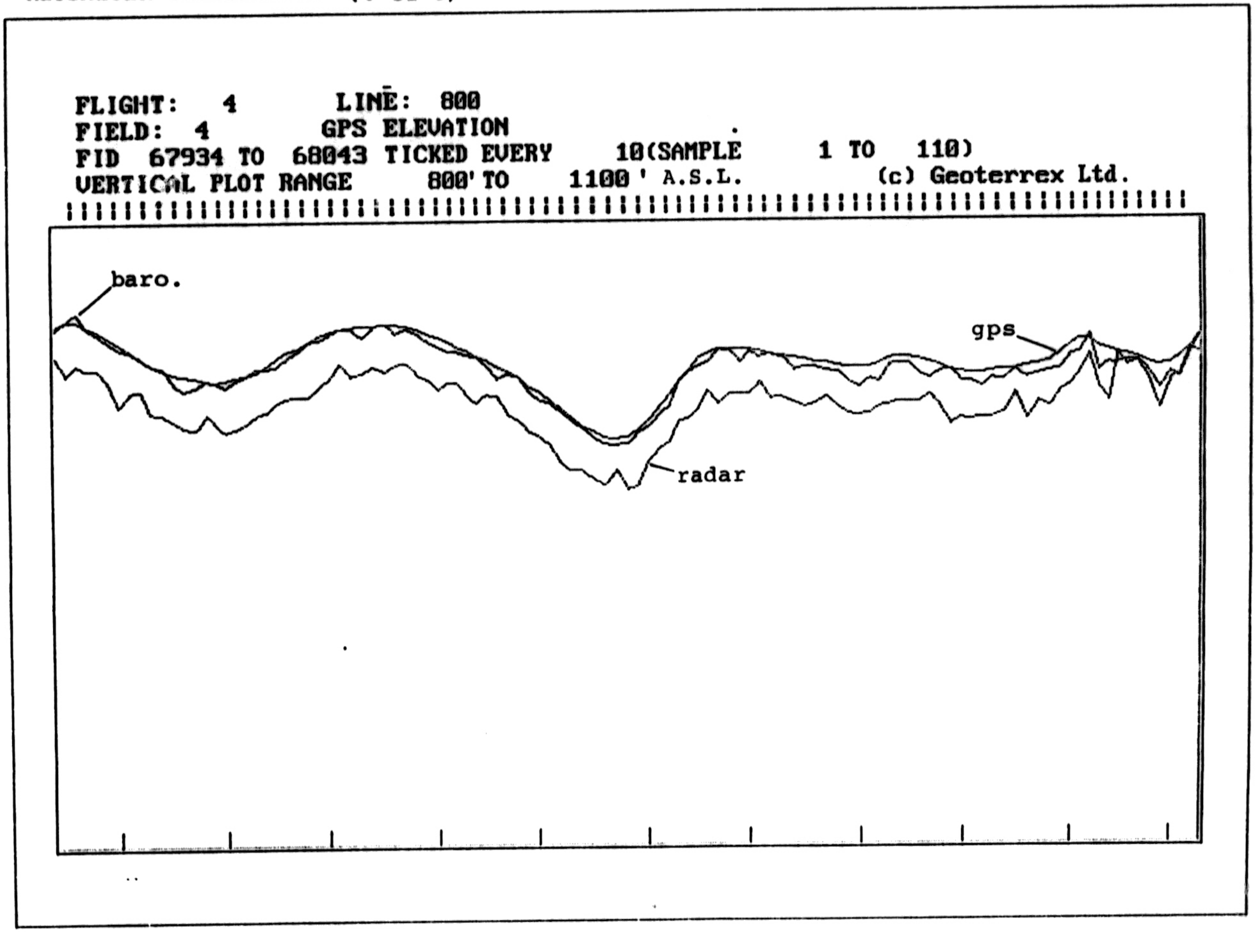


Figure 12

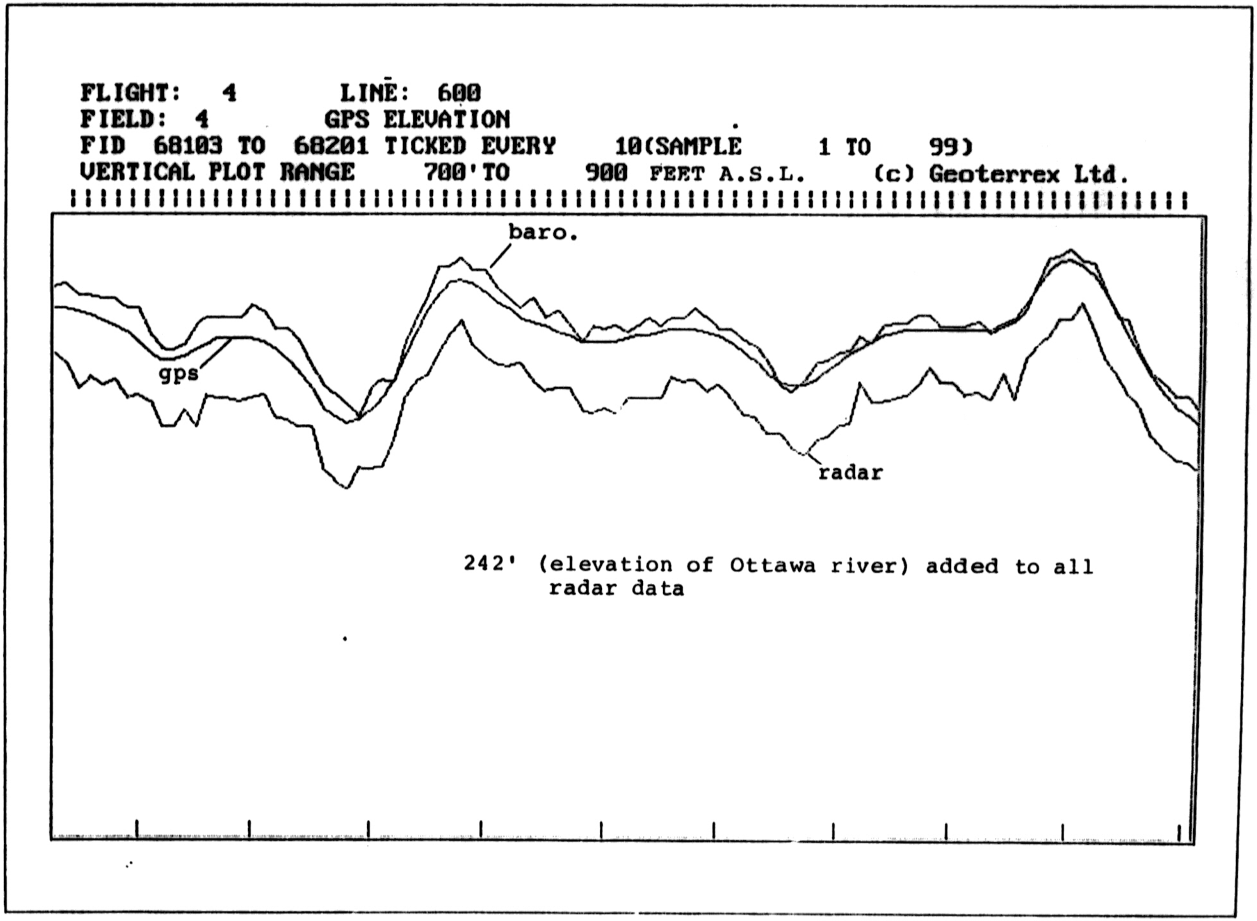

FLIGHT: 4 LINE: 600
FIELD: 4 GPS ELEVATION
FID 68103 TO 68201 TICKED EVERY 10(SAMPLE 1 TO 99)
VERTICAL PLOT RANGE 700'TO 900 FEET A.S.L. (c) Geoterrex Ltd.
baro.
gps
radar
242' (elevation of Ottawa river) added to all radar data

Figure 13

EFFECT OF TEMPERATURE ON BAROMETRIC ALTITUDE

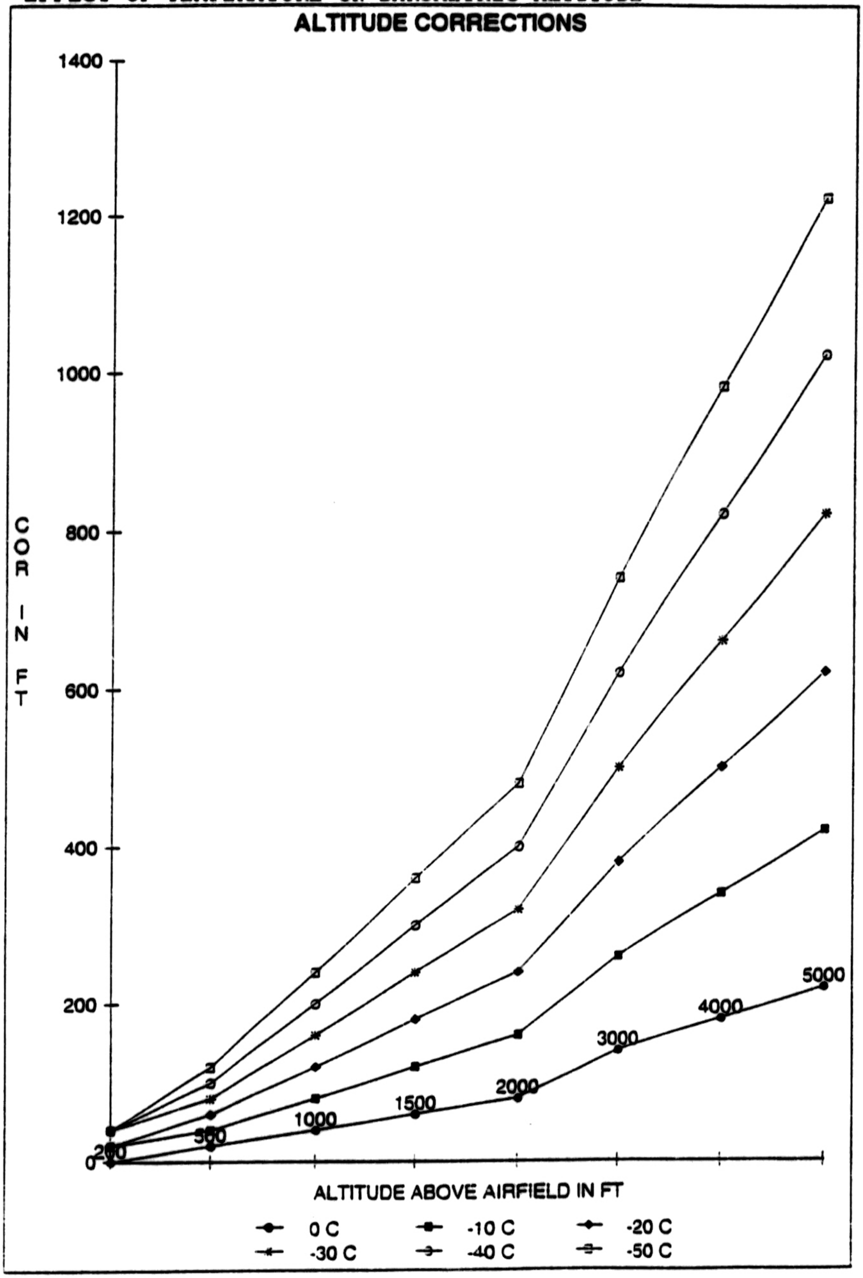


Figure 14

COMPARISON OF GPS AND BAROMETRIC ALTIMETERS

FLIGHT: 157
FIELD: 9 GPS ELEVATION
FID 70300 TO 71680 TICKED EVERY 20 SECONDS
VERTICAL PLOT RANGE 600 TO 2100 METRES (c) Geoterrex Ltd.

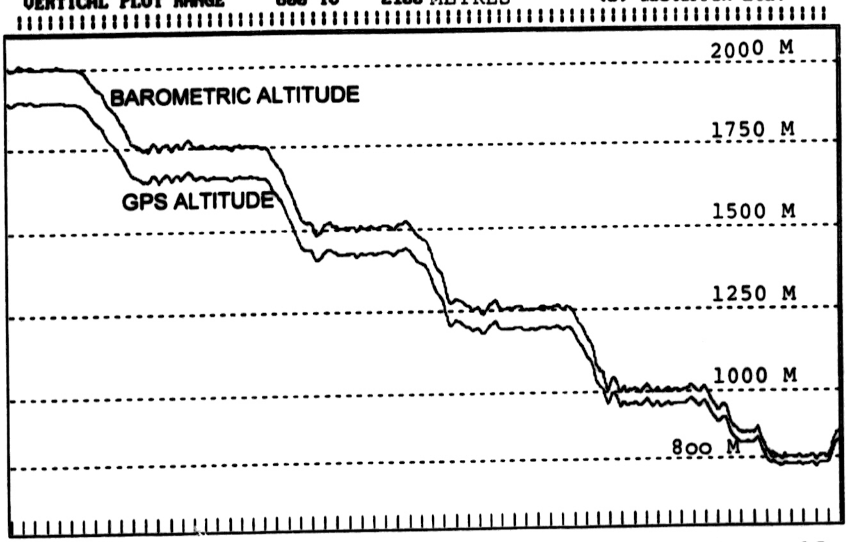


Figure 15

Daily Barometric Altimeter Calibrations
In order to reduce the effects of atmospheric pressure changes upon the barometric altimeter, it was set at the airport elevation just before take-off; and after landing, the difference between the barometric altitude and airport elevation was recorded. Any drift of 100' or more was distributed evenly across the flight.

Ground Station Calibration
A cross of one-metre stations was measured around both the main and remote magnetic base station sensors to avoid steep gradients.

Both ground station magnetometers were compared with the airborne magnetometer by parking the aircraft as close as possible to each ground sensor and comparing simultaneous recordings. This is illustrated in figures 16 and 17.

GPS Navigation Test
The GPS navigation system was tested for systematic errors by comparing its position (after differential correction) with that of the on-board camera when flying a cloverleaf test. An along-track offset, or lag, of 0.35 seconds was noted and corrected by shifting the GPS field with regard to the fiducial field. The GPS flight path of the calibration test at Bourget on July 11, 1995, is plotted at 1:1,000 scale in figure 18. This figure reveals errors of navigation/path recovery of up to 22 metres, after the differential correction, GPS lag and pilot error are applied. The co-ordinates of the crossroads were derived from a GPS receiver mounted at the crossroads by the Geological Survey of Canada: WGS84/NAD83: latitude 45° 26.61666'N, longitude 75° 07.61900'W. These were converted to UTM metres of: x - 490,069.3, y - 5,032,239.7.

The exact NAD83 co-ordinates of the GPS base station antenna in Watson Lake were determined by running the GPS receiver for two full constellation passes (48 hours) and calculating the mean position of the antenna: latitude 60° 08' 47.466"N, longitude 128° 50' 49.608"W. During the survey, this mean position was monitored.

Field Crew
The base of field operations was Watson Lake, Yukon Territory. A remote ground station was operated at Fort Nelson, British Columbia.

Pilots:	S. Malle, E. Heisler, T. Stenton, R. Webster, G. Stonehouse
Electronics Operators:	L. Denner, K. Lamirande, J.R. Grenier, T. Payne, D. Patzer
Engineers:	C. Marshall, C. Ivimey, M. Nash, R. Constapel

COMPARISON OF AIRCRAFT AND REMOTE BASE STATION MAGNETOMETERS

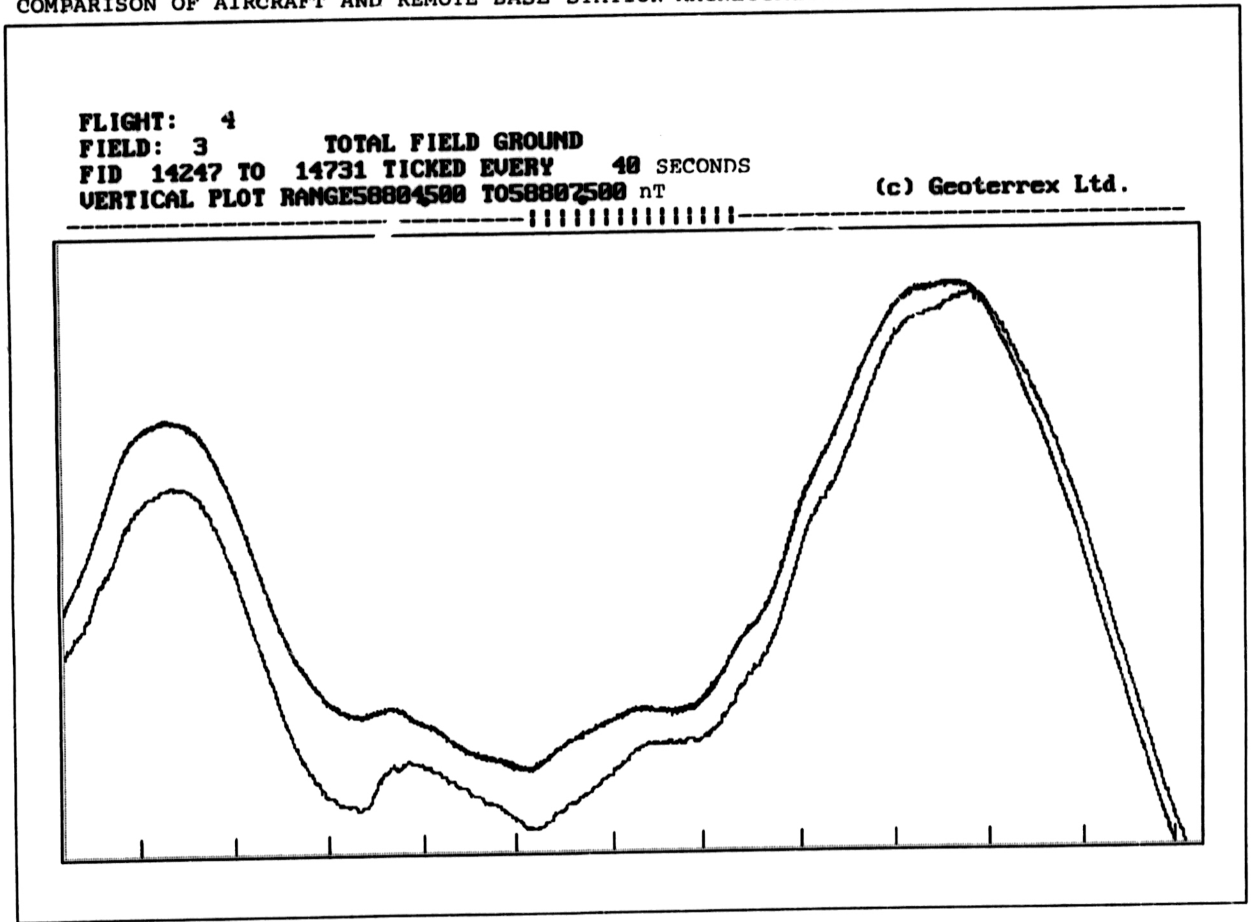


Figure 16

COMPARISON OF AIRCRAFT AND MAIN BASE STATION MAGNETOMETERS

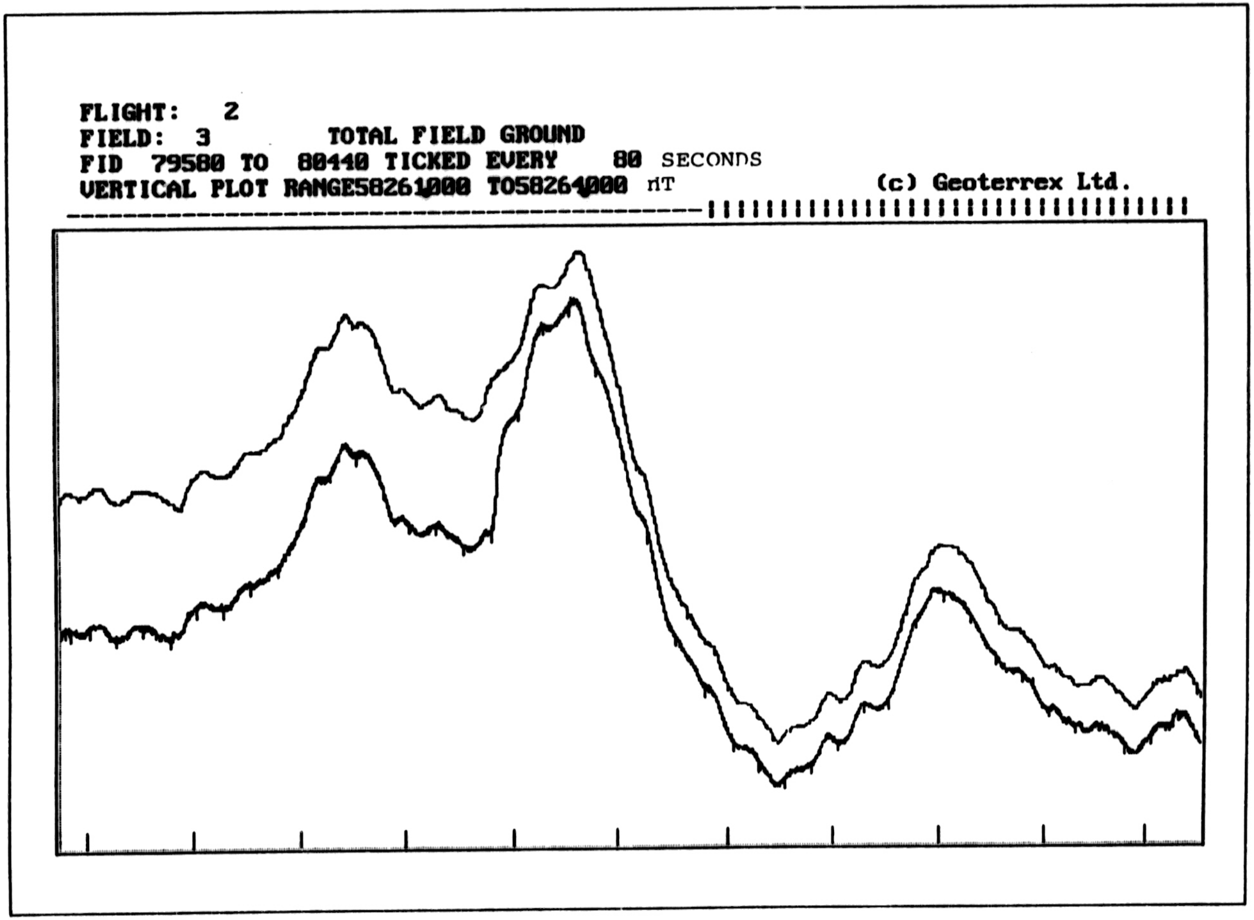


Figure 17

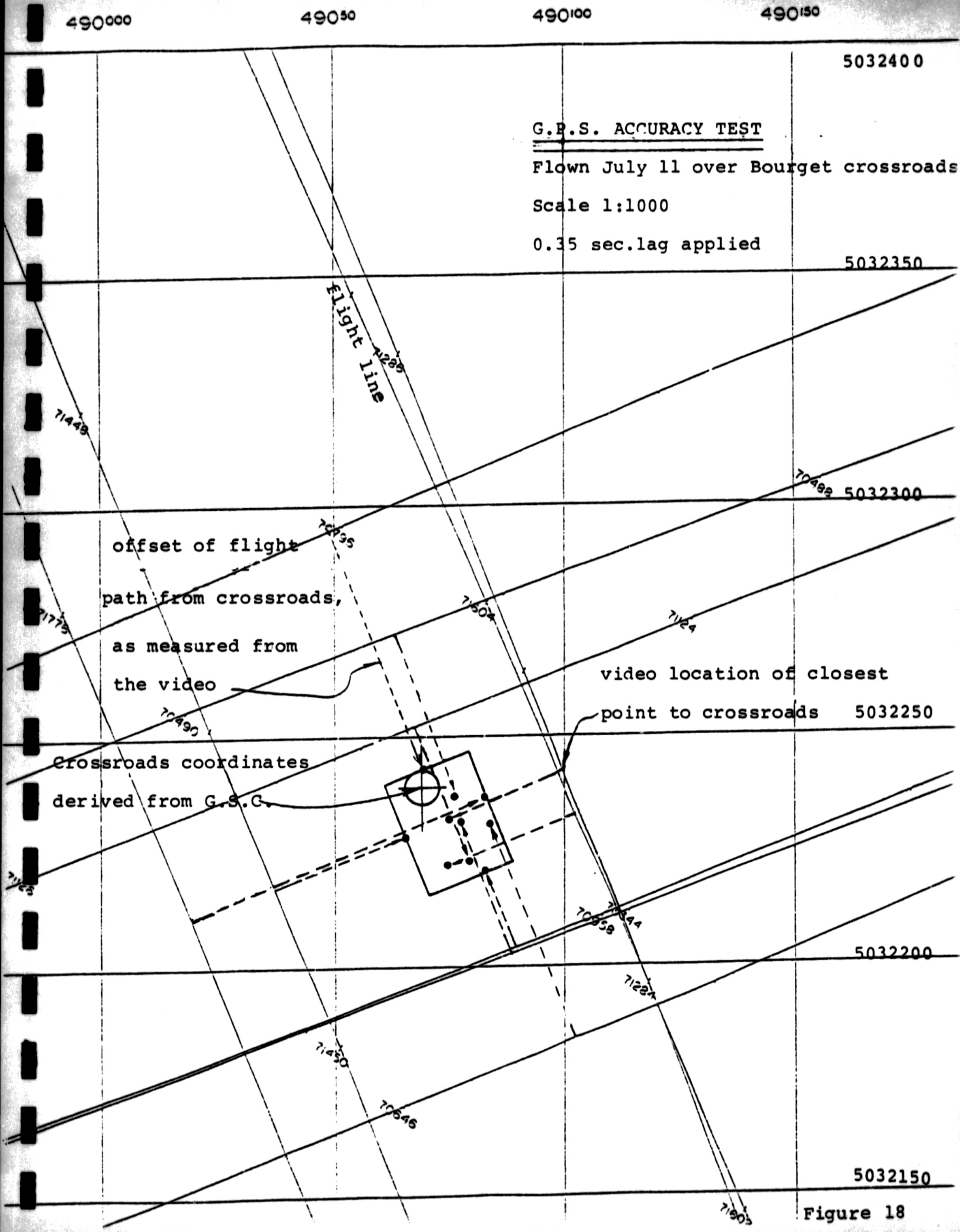

490000
49050
490100
490150
5032400
G.P.S. ACCURACY TEST
Flown July 11 over Bourget crossroads
Scale 1:1000
0.35 sec.lag applied
5032350
Flight line
5032300
offset of flight
path from crossroads,
as measured from
the video
video location of closest
point to crossroads
5032250
Crossroads coordinates
derived from G.S.C.
5032200
5032150

Figure 18

Data Processors/ Geophysicists:	K. Ireland, B. Field, D. Skubiski, B. Schacht, Y. Kroupoderov
Remote Ground Station Operator:	R. Grouette
Gov't Inspector:	Peter Stone, July 28 - August 1 and October 2-5, 1995

Production Statistics

In addition to these 51,244 km in northern British Columbia, 56,909 km of data were also flown concurrently. The following statistics are for this joint operation of 108,153 km. Production began on July 26, 1995, and ended on March 4, 1996. The average daily production was 485 km. Total flying hours were 676.6, for an average of 3.0 hours/day and an average production rate of 160 km/hr.

3. QUALITY CONTROL AND COMPILATION PROCEDURES

In the Field

After each flight, all analog records were examined to assess the noise level of the recorded total magnetic field, focusing on the hi-pass filtered trace generated from the magnetic data and displayed on the charts. Altimeter deviations from the prescribed flying altitude were also closely examined on the computer screen as well as the general conditions of the diurnal activity, as recorded on the base stations. Accurate daily logs were kept describing the quality of all recorded measurements.

All digital data were verified for validity and continuity. The data from the aircraft and base stations was transferred to the PC's hard disk. Basic statistics were generated for each parameter recorded (magnetics, altimetry, GPS positioning, time); these included the minimum, maximum and mean values, the standard deviation and any null values located. Editing of all recorded parameters for spikes or datum shifts was done using a fourth difference routine, followed by final data verification via an interactive graphics screen with on-screen editing and interpolation routines. Any of the recorded parameters could be plotted back at a suitable scale on the field pen plotter.

The quality of the navigation was controlled on a daily basis by recovering the Trajecto corrected GPS flight path. The Trajecto correction procedure employs the raw ranges from the base station to create improved models of clock error, atmospheric error, satellite orbit, and selective availability. These models are used to improve the conversion of aircraft raw ranges to aircraft position. The Trajecto corrected GPS flight path was plotted back daily in the field on the pen plotter and checked for speed busts. At the beginning of the survey, the GPS positions were verified against visual points and found to be correct without exception, using 1:50,000 scale topographic maps.

Checking all data for adherence to specifications was carried out in the field by the Geoterrex field operations manager/data technician. Any marginal cases were referred to geophysicists in Ottawa and the Technical Inspector.

The GMAPS field software essentially duplicates our office capabilities. We took processing through to (and inclusive of) contouring/imaging.

To summarize the field compilation/validation procedures:

1. Read and reformat field tapes (from both the air data and base stations) in the process of loading the digital data onto the field computer's hard disk.
2. Generate error listings and statistics on all recorded parameters (altimetry, magnetics, navigation data) to verify continuity and validity.
3. Edit any bad values via a 4th difference routine or an interactive graphic screen editing program.
4. Apply time adjustments for system lag to the magnetic data.
5. Apply all necessary conversions, time adjustments and corrections to the navigation data.
6. Plot back the GPS flight path in UTM metres at any desired scale on the field plotter.
7. Identify any bad flight path by calculating the average speed between each point and apply any necessary corrections.
8. Merge edited magnetics and final field X, Y positions into a main file.
9. Back-up and return all data to the office to finalize the processing.

In the Office

All necessary verification, editing and correction of flight path, altimetry and diurnal records was done in the field. The compilation and processing of the survey data from field to final digital and map products in Geoterrex's Ottawa office was directly supervised at all stages by both the Project Manager and the Geophysical Processing Manager. After the processing steps were completed to the satisfaction of these individuals, the results were submitted to the Technical Inspector.

Details of the compilation procedures are summarized below and in figure 19.

1. Restore all field data onto the main processing network.
2. Plot back all final flight path.
3. Verify the data quality.
4. Apply altitude and noise corrections to the magnetics.
5. Level the magnetics by examining various computer listings that provide information on the nature of the field, the differences and the corrections applied at each intersection, along with profile plots displaying flight path, levelling corrections applied and variation of the diurnal field.
6. Grid and plot the preliminary total intensity contours at 1:50,000 scale.
7. Examine the preliminary contours for residual levelling and positioning errors, gridding artifacts, diurnal noise and any trending problems.

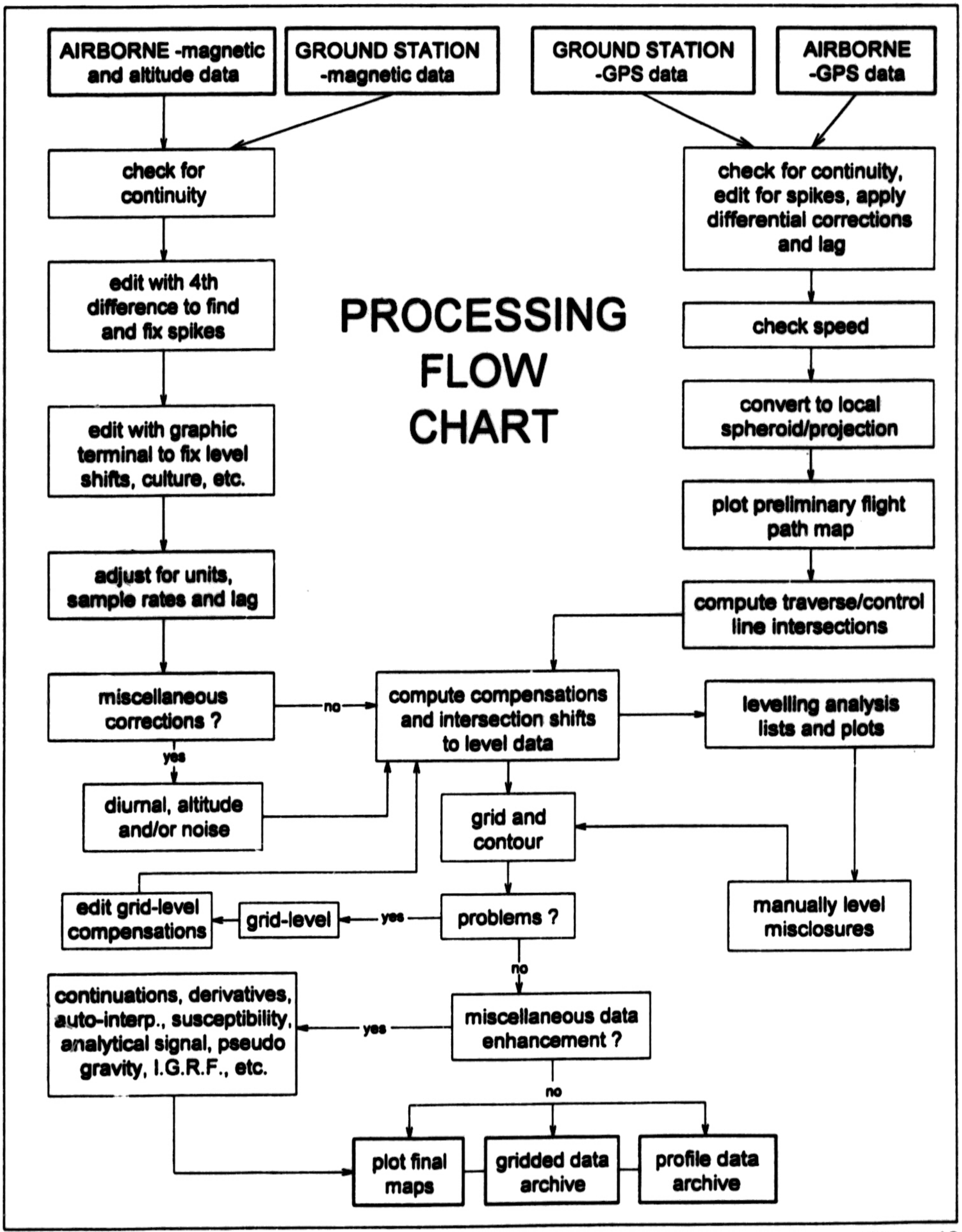

AIRBORNE -magnetic and altitude data
GROUND STATION -magnetic data
GROUND STATION -GPS data
AIRBORNE -GPS data
check for continuity
check for continuity, edit for spikes, apply differential corrections and lag
edit with 4th difference to find and fix spikes
PROCESSING FLOW CHART
check speed
convert to local spheroid/projection
edit with graphic terminal to fix level shifts, culture, etc.
plot preliminary flight path map
adjust for units, sample rates and lag
compute traverse/control line intersections
miscellaneous corrections ?
no
compute compensations and intersection shifts to level data
levelling analysis lists and plots
yes
diurnal, altitude and/or noise
grid and contour
edit grid-level compensations
grid-level
yes
problems ?
manually level misclosures
no
continuations, derivatives, auto-interp., susceptibility, analytical signal, pseudo gravity, I.G.R.F., etc.
yes
miscellaneous data enhancement ?
no
plot final maps
gridded data archive
profile data archive

Figure 19

8. Apply all necessary corrections.
9. Re-grid and re-contour the total intensity magnetics to verify that all necessary corrections have been properly applied.
10. Apply multi-step grid-based levelling techniques to remove short period diurnal events.
11. Submit the coloured total intensity contour maps to the technical inspector for approval.
12. Plot ten copies of the approved total intensity coloured contours, with flight path, planimetry and title information.
13. Archive all final, approved data, in the necessary format.

Details of Total Magnetic Field Compilation

Editing

All editing and correction routines were approved by the Technical Inspector. Noise spikes down to 0.150 nT were removed automatically and more complex errors were flagged by the program and corrected manually.

Noise Corrections

No filters were applied to any altitude data. Many lines throughout the survey area have magnetic noise, about 0.10 - 0.15 nT in amplitude and 3 - 10 samples in wavelength. It usually appears in a characteristic pattern of 3 bursts: a central stronger burst of 20 seconds flanked by 2 weaker bursts about 10 seconds wide, separated from the central burst by about 20 seconds. The entire zone is surrounded by a couple of minutes of weaker noise of about 2 sample wavelengths. Line 148 was flown on flights 129 and 134 and the noise was <u>not</u> located in the same place. However, flight 134 covered a solid block of lines in the area and the noise coincided precisely from line to line. Furthermore, our pilot noted interference on his radio whenever he encountered this magnetic noise; and, conversations with local pilots confirmed that some sort of radar beams were commonly encountered in the area, above 7,500 feet. Tests revealed the following filter (cut-off 0.065 cycles/sample interval, roll-off 0.034 cycles/sample interval) removed the noise without affecting even the shallowest surficial source anomalies. Figure 20 shows the noise at its worst. Figures 21 and 22 demonstrate that this filter does not alter any real (i.e. ground-source) anomalies.

Altitude Variation Corrections

The average vertical gradient for the Earth's magnetic field in this area is near 1 nT/30 m. Thus, without exceeding the altitude specification (±30 m), a pilot could create false anomalies approaching 2 nT; although this extreme case is probably never encountered. Our cross-correlation technique looks for coincidence of wavelengths between the altitude and the total field; after a suitable band-pass. Most altitude "bumps" have periods between about 8 and 32 seconds.

Radar (?) Noise Filter

Frequency Domain c.o. 0.065 r.o. 0.034 at 5 samples/sec

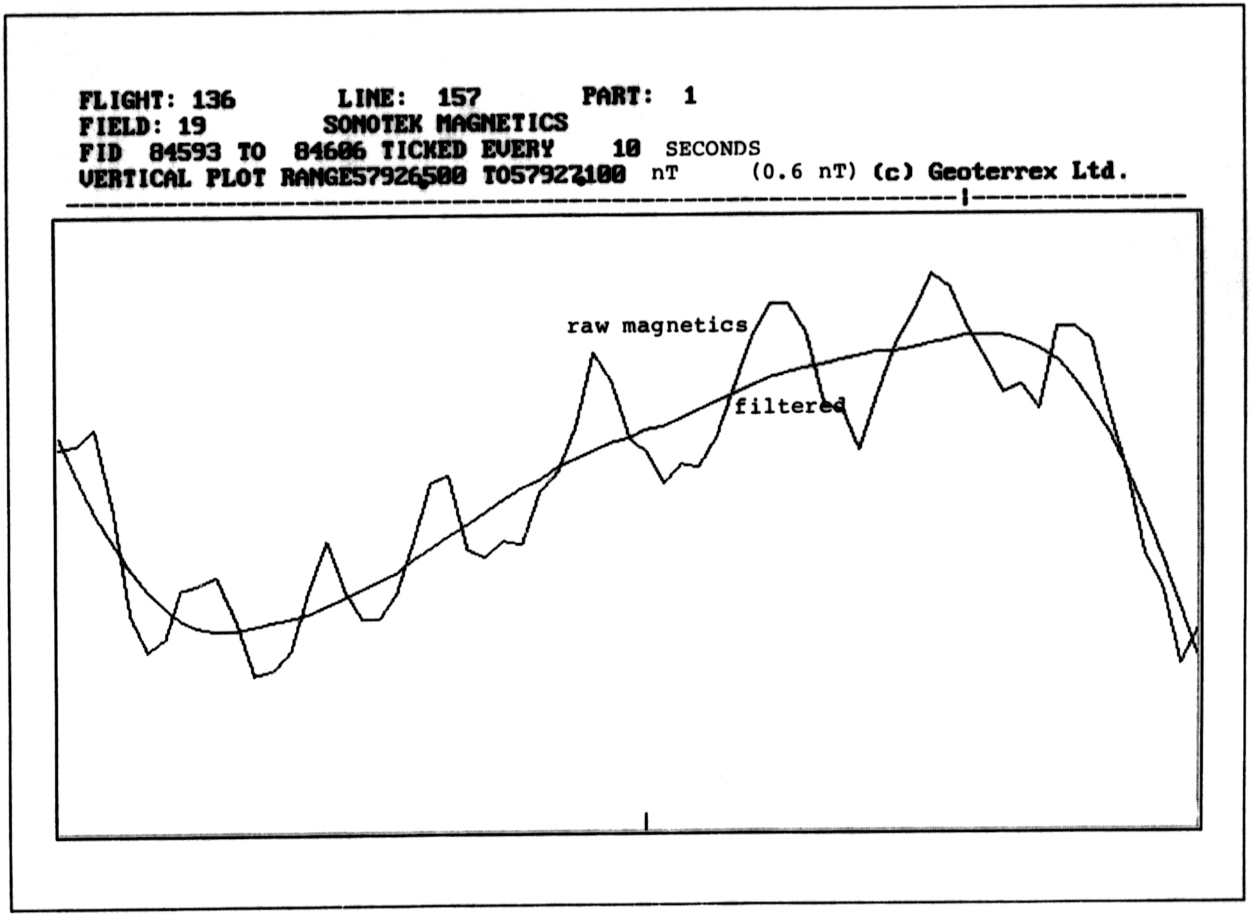


Figure 20

Radar (?) Noise Filter

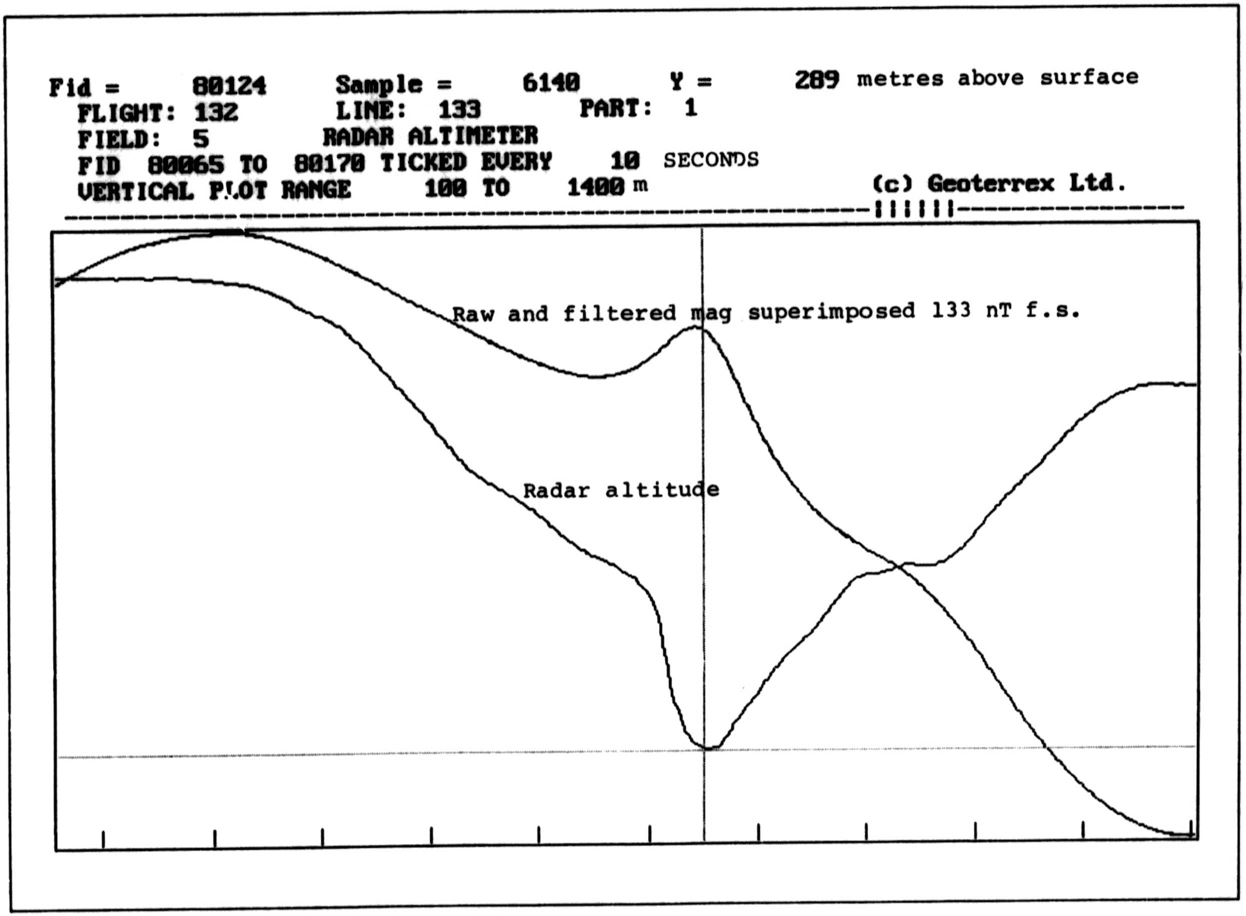


Figure 21

Radar (?) Noise Filter

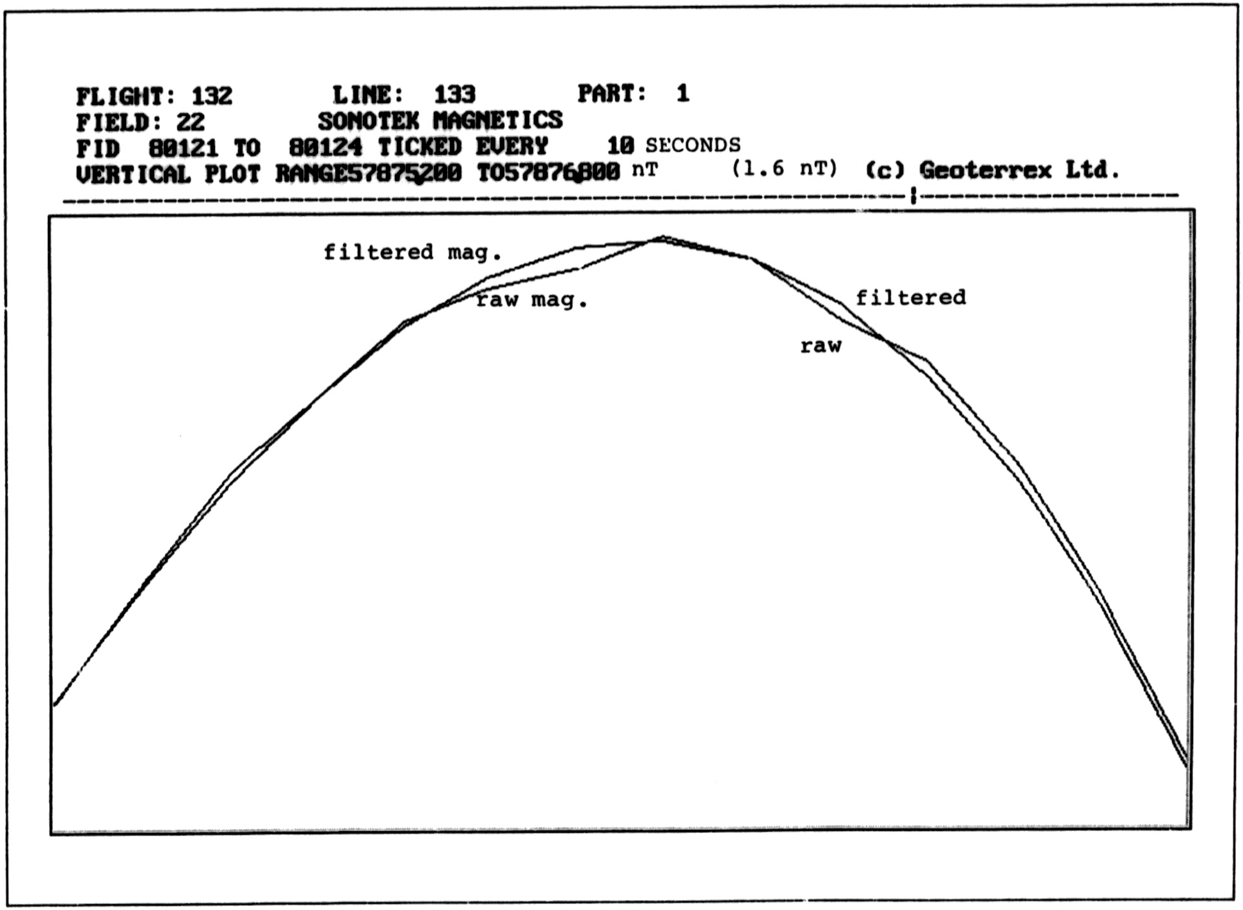


Figure 22

When correlations were found, corrections were made with a vertical gradient of up to 0.022 nT/m, depending upon the degree of correlation. Figure 23 shows typical altitude variations with the raw and corrected total fields. This correction does not alter the magnetics for the long-period altitude variations involved in draping.

Diurnal Magnetic Variation Corrections

Ground station data was checked for man-made disturbances. A few were found on the remote station records and edited out using an interactive editing program with a graphics monitor.

Records from both base and remote magnetic ground stations were examined to determine the degree of correlation of long wavelengths. Insufficient correlation was observed between these two stations to suggest that removal of even the long-wavelength component of the ground station data from the aeromagnetic data would improve the levelling procedure (see figure 24).

Occasional malfunctions of the remote base station at Fort Nelson resulted in gaps in coverage of about 1%.

Control-Line Levelling

Introduction

The lines (traverse lines) and tie-lines (control lines) of an aeromagnetic survey form a network, and the points where they cross one another are called intersections. At each intersection, it is easy to interpolate the magnetic value on the line and on the control line from adjacent values. In theory, the two magnetic values at the intersection should be identical. In practice, they will usually be different as a result of:

1. Time variation of the magnetic field.
2. Heading effects. Our cloverleaf test revealed no significant heading effects.
3. Altitude differences. Since the earth's magnetic field varies with altitude above the ground, any difference in flight altitude will cause a difference in magnetic value.
4. Position errors. These have little effect in areas of low magnetic gradients, but can introduce large differences in steep gradients.

In the levelling process, it is assumed that most of the required level adjustments will vary smoothly along each line or control line, in the same manner as the time variations of the magnetic field.

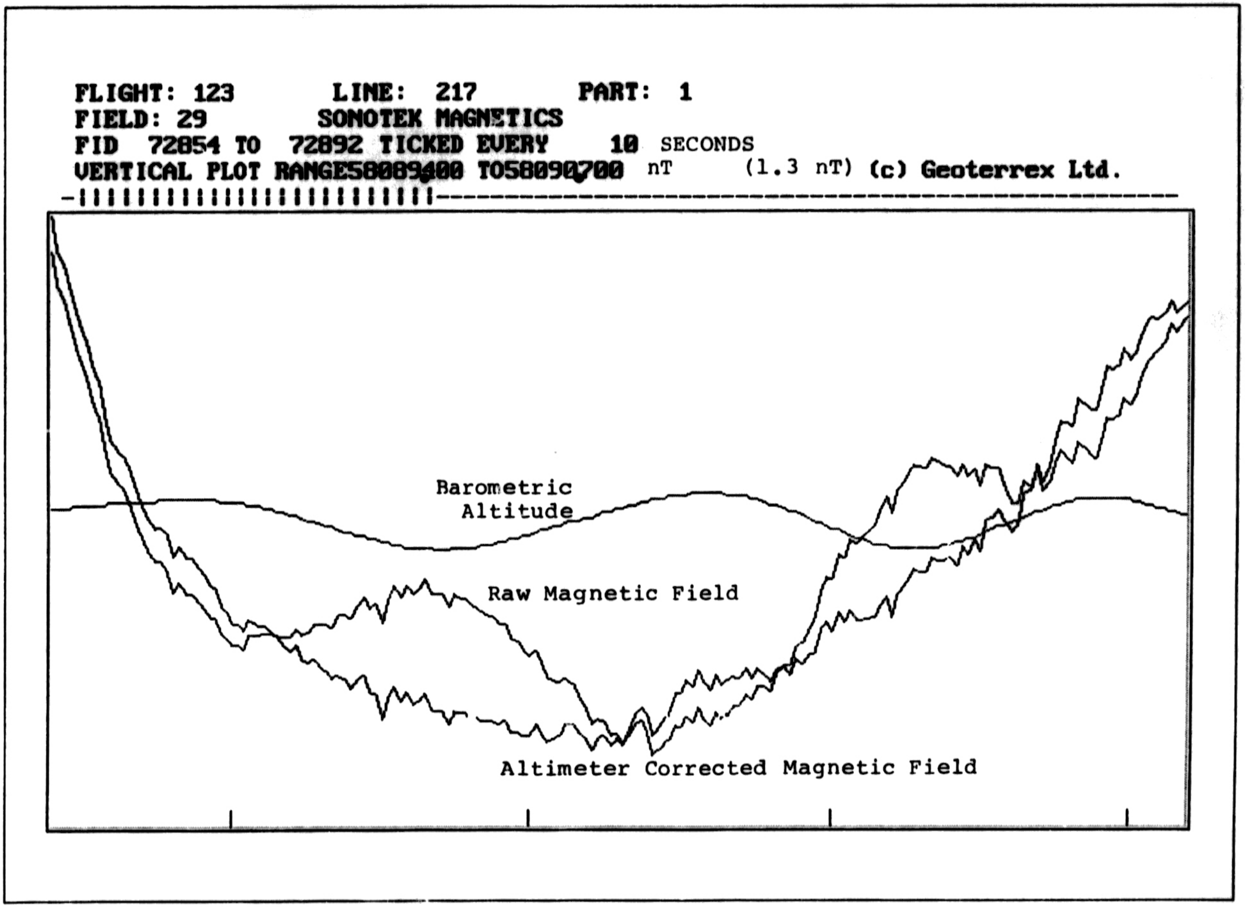

FLIGHT: 123 LINE: 217 PART: 1
FIELD: 29 SONOTEK MAGNETICS
FID 72854 TO 72892 TICKED EVERY 10 SECONDS
VERTICAL PLOT RANGE58089400 TO58090700 nT (1.3 nT) (c) Geoterrex Ltd.
Barometric Altitude
Raw Magnetic Field
Altimeter Corrected Magnetic Field

Figure 23

CORRELATION OF MAIN AND REMOTE MAGNETIC BASE STATIONS EVENTS

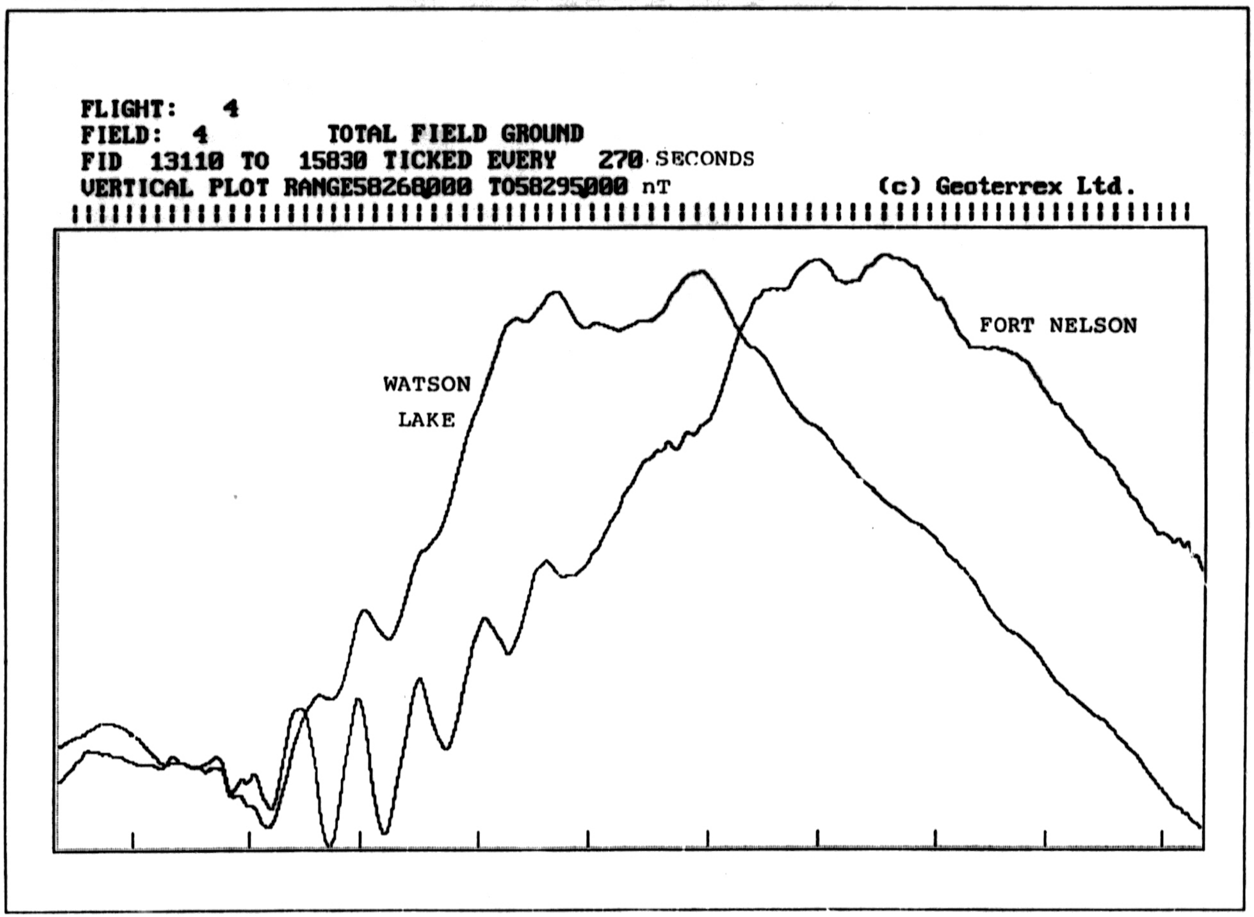


Figure 24

The total levelling adjustment did not normally exceed one nT per kilometre; however using the diurnal as a guide, some higher rates of correction were applied in areas of rapid diurnal variation (with the approval of the Technical Authority).

There were some intersections which could not be fitted with smooth level adjustments on both line and control line. These were attributed to errors in the aircraft position, and the flight path was adjusted to change the L-T (line minus control line) value to one which could be fitted by smooth adjustments; these movements were limited to 30 metres (2 sample intervals).

Mathematical Analysis

The network of traverse lines and control lines are assumed to lie in the X-Y plane (see figure 25). The position of an intersection "i" is then characterized by the coordinates (x,y) and times t^L and t^T. The measured magnetic field is characterized by a value on the vertical axis (Z axis) perpendicular to the X-Y plane. The difference between the magnetic field values on the line and the control line (the L-T difference) at intersection"i" is the misclosure M.

Outline of Process

The first stage of the levelling process is the calculation of the line and control line level adjustment at each intersection. These vary smoothly along a line or control line and define the levelled baseline of the magnetic profile. The line and control line level adjustments (A^L and A^T respectively) account for the diurnal. The level adjustments are calculated with two averaging operations, MOYA and MOYB (MOY is from the French work MOYENNE, meaning average). MOYA removes the slowly varying component of the misclosures, and MOYB removes the rapidly varying component. After MOYA and MOYB, at the "i" intersection, the misclosure remaining after adjustment, R, is given by

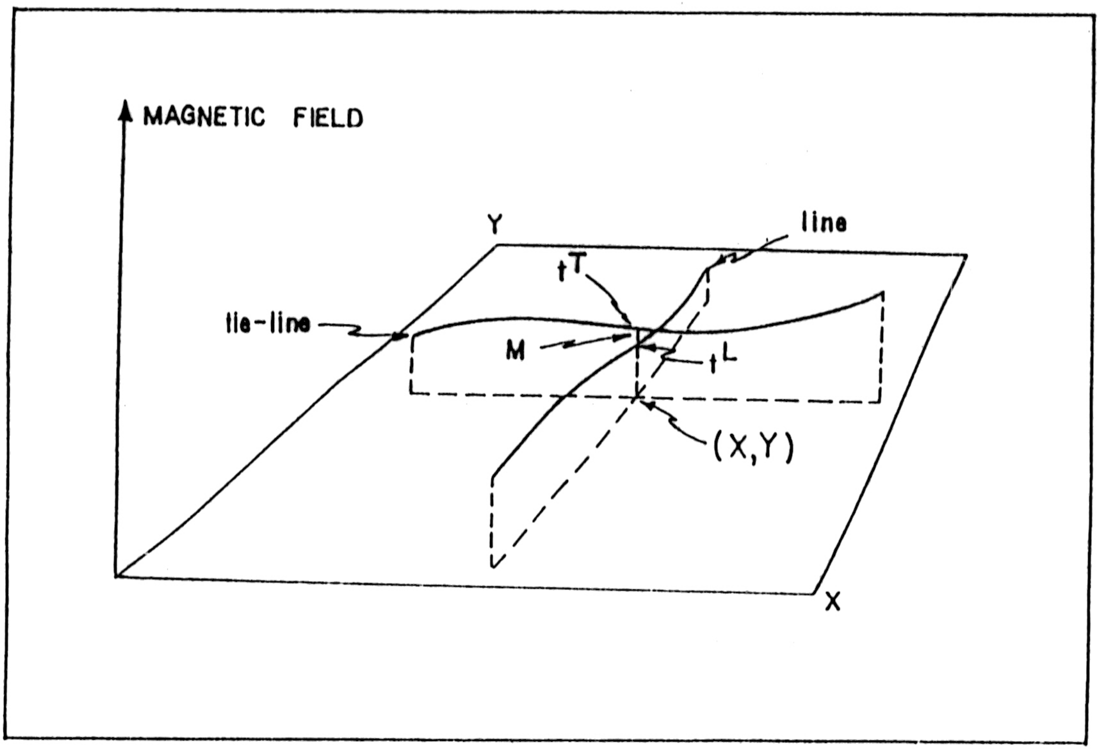
$$R = M + A^L - A^T \qquad ....(1)$$

The next stage consists in tilting the line baseline by a maximum allowed tilt of T to reduce the misclosure R to zero.

If $\quad |R| \leq T, \qquad ...(2)$

then $\quad M + AA^L - A^T = O \qquad ...(3)$

where $\quad AA^L = A^L - R \qquad ...(4)$



PARAMETRIC REPRESENTATION AT INTERSECTION "i"

FIGURE 25

is the new line adjustment.

If the remaining misclosure R cannot be reduced to zero within the maximum allowed tilt T, the position of the intersection instead is shifted in the X-Y plane to the point closest to the intersection (within a maximum allowed displacement) where the relation

$$R + D^L - D^T = O \qquad \text{...(5)}$$

is satisfied. D^L and D^T are the differences, (or magnetic value at the new intersection position minus the magnetic value at the original intersection position). The initial misclosure M is then corrected to give

$$M_{corr} = M + D^L - D^T \qquad \text{...(6)}$$

such that

$$M_{corr} + A^L - A^T = O \qquad \text{...(7)}$$

If the remaining misclosure R cannot be reduced to zero within the maximum allowed displacement, the maximum allowed tilt is increased and the tilting calculation (equations 2 to 4) is reapplied. If R is still not reduced to zero, the maximum allowed displacement is also increased and a tilt and shift are applied simultaneously to the intersection. The position of the intersection is now shifted in the X-Y plane to a point where the relation

$$|R + D^L - D^T| \leq T \qquad \text{...(8)}$$

is satisfied. The intersection can be moved to the closest point or to the point with the smallest tilt which satisfies equation (8). The first option is usually preferred. After tilting and shifting of the intersection, the misclosure and line compensations are corrected to give

$$M_{corr} + AA^L - A^T = O \qquad \text{...(9)}$$

where

$$AA^L = A^L - (R + D^L - D^T) \qquad \text{...(10)}$$

is the new line level adjustment, and

$$M_{corr} = M + D^L - D^T \qquad \text{...(11)}$$

is the corrected misclosure.

The intersection is flagged if it is closed using condition (8) (relaxed specifications). If the misclosure R at the intersection still cannot be reduced to zero under relaxed specifications, it is specially flagged as a "bad" intersection. This requires checking of the flight path recovery. The data set can then be re-levelled automatically or the bad intersection can be closed manually.

The levelling process can thus be summarized as follows:

Compensation:
- MOYA on the control lines (run 1)
- MOYA on the lines (run 1)
- MOYA on the control lines (run 2)
- MOYA on the lines (run 2)
- MOYB on the lines
- MOYB on the control lines (twice)

If necessary, Tight specifications:
- Tilt the line baseline, or
- Shift the position of the intersection

Relaxed specifications:
- Tilt the line baseline, or
- Shift the intersection and tilt the line baseline

If M ≠ O: Bad intersection.

The differences at the intersection points are tabulated by printed outputs from the computer program for each traverse line and control line in a readily comprehensible form.

Step 1: *Traverse Line Minus Control Line Printout (digital file)*

BARO ALT CL	BARO ALT. TL	RADAR ALT. CL	RADAR ALT. TL	DIURNAL GRADIENT CL	DIURNAL GRADIENT TL	DIURNAL CL	DIURNAL TL	RAW MAG CL	RAW MAG TL

NO. CL	NO. TL	FLT NO. CL	FLT NO. TL	DIRECTION CL	DIRECTION TL	X metres	Y metres	FID CL	FID TL	SCAN CL	SCAN TL	DIURNAL TL-CL	MAG TL-CL

GRADIENT CL 21 values	GRADIENT TL 21 values

Step 2: *Final Levelling Analysis Printout (digital file)*

CL No.	TL No.	ORIGINAL TL-CL	ORIGINAL CL LEVEL ADJUST.	ORIGINAL TL LEVEL ADJUST.	2ND TL-CL	DIFF. IN LEVEL ADJUST FROM PRECED. INT. (CL OR TL)	DIUR. DIFF. FROM PRECED. CL OR TL AT INT.	BARO. ALT. DIFF. TL-CL	MAG. GRADIENT INDICATOR (CL OR TL)

2ND TL LEVEL ADJUST	CL SHIFT	TL SHIFT	FLT. DIR. CL	FLT. DIR. TL	FINAL TL-CL	FINAL CL LEVEL ADJUST.	FINAL TL LEVEL ADJUST	DIFF IN FINAL LEVEL ADJUST FROM PRECED. INT (CL OR TL)

A graphical plot of the final total field level adjustments along the traverse lines, and control lines was prepared; it also showed the diurnal from both the base stations. When final levelling adjustments were applied, all control lines and traverse lines yielded identical values at intersections.

Gridding and Contouring

The grid interval was 100 m. A minimum curvature routine was used to create the grids. This minimum curvature routine is based upon the work of:

Briggs, I.C., 1974, Geophysics, V39, p. 39-48.
Swain, C.J., 1976, Computers and Geosciences, V1, p. 231-240.
Webring, M., 1981, U.S.G.S. Open File Report, 81-1224.

It minimizes curves in the grid while honouring both traverse and control line data.

The 1983 North American Datum was used. In addition to latitude and longitude, U.T.M. metres were also calculated with a false northing of 0 metres, a false easting of 500,000 metres, and a scale factor of 0.9996. The 123 and 129°W central meridians were used.

Isogam contour maps were produced from this grid by a computer contouring program. The contours faithfully reflect the final magnetic values along each line; no smoothing or filtering of these values was permitted in the gridding or contouring. Preliminary contour maps were plotted at 1:50 000 scale for inspection. The grid used for the 1:50 000 scale maps was also used for the final 1:100 000 scale maps.

Absolute total field magnetic values appear on the final maps (not relative values above some arbitrary datum). Contour intervals of two, ten, fifty and one hundred nanoTeslas are shown using different black line weights. Magnetic depressions are indicated by "shark's teeth" placed around the inside of the lowest contour. The direction of the contour labelling faces up gradient.

One colour bar was used for all map sheets in the British Columbia portion of this survey.

Grid Levelling
Examination of the control-line levelled contours revealed a significant amount of noise resulting from magnetic diurnal micropulsations. With the aircraft crossing control-lines at one minute intervals, all micropulsations shorter than 60 seconds cannot be corrected by control-line levelling. In his 1991 paper in Exploration Geophysics (V22, p591-592) B.R.S. Minty described a method of "microlevelling" a magnetic grid to remove subtle levelling errors. This method's main weakness is a tendency to broaden or remove anomalies running parallel to the flight lines. In order to ensure that no real anomalies were altered, Minty's method was improved by intensive manual intervention by the project geophysicist. Profiles matching all traverse and control-lines were taken off the grid of proposed diurnal corrections and examined together with profiles of radar altitude, barometric altitude, diurnal variations from both base stations, and the magnetic field. Any proposed correction which was altering a potentially real (i.e. ground-source) anomaly was edited from the correction profile. These edited correction profiles were then added to the magnetic total field as a second levelling correction; and control-line levelling was re-applied. No

movement of intersection locations was permitted in this second control-line levelling.

The resulting contours still revealed some probable noise of diurnal origin. On short segments of a few lines, diurnal micropulsations were not detected by the grid-levelling technique because their extremely short periods mimicked real anomalies. Examination of all the profile data, as described above, for each of these clusters of single-line features, allowed the geophysicist to manually (interactive graphics terminal with curve fitting software) edit the magnetic field profiles, removing all anomalies whose origins were undoubtedly not real. Control-line levelling was then re-applied. The lines involved in this final stage of diurnal correction were:

FLIGHT	LINE	PART	FIDUCIALS
152	162	1	start-76700
98	267	1	90200-90250
98	267	1	90350-90650
99	272	1	74850-75020
98	273	2	89630-89850
74	353	1	start-64800
74	353	1	65760-65960
74	354	1	60450-61090
72	358	1	70300-70470
74	370	1	67700-67930

Steps Involved in Creating Completely Digital Maps

The process can be divided into two paths: one for vector data and another for raster data. The CAD software used for this job was MicroStation (v.5) (.dgn file extension) and an add-on package called Descartes (.hmr file extension).

Vector Data

1. (a) Digital topography provided in dxf format by the GSC (utm metres).
   (b) Topography imported into MicroStation and separated into individual MicroStation design files as defined by sheet extents according to final sheet layout (1:100,000 scale).
   (c) Colour, weight, line style and level attributes applied.

2. (a) Master title surround created - neat lines, titles, colour bar, credits, technical notes, etc. - with guidance from the GSC.

3. (a) Merge master title dgn with digital topography dgn - rotate and move title information to register with topography.

   (b) Edit text, latitudes, longitudes, index block, adjacent sheets, etc. which are unique to each sheet.

4. (a) Create Calcomp 907 format plot files, on a 1:100,000 sheet basis, of final total field contours and flight path.
   (b) Convert to dxf (in metres).
   (c) Import contours and flight path into MicroStation dgn file containing previously merged title surround and topography.
   (d) Apply appropriate colour, weight, line style and level attributes to contours and flight path.
   (e) Edit irregularities.

Raster Data

1. (a) From final Geoterrex format grids, part grid out individual grids on a sheet by sheet basis.

2. (a) Convert each grid to Geosoft format and view with Geosoft using the zone file suggested by the GSC.
   (b) Geosoft grids are then converted to tiff format (40 m cell size). This conversion generates a registration file.

3. (a) Tiff images are then imported into finalized MicroStation dgn files. A MicroStation add-on, Descartes, converts the tiff file to its own native format (.hmr) and it is positioned using the information in the registration file created in the grid-to-tiff conversion.
   (b) Image colours are edited to match the zone file. Exact colours are not maintained throughout the grid-to-tiff and tiff-to-hmr conversions.
   (c) All cells outside neat lines are changed to the background colour (white).

Creating Archives

MicroStation's Descartes creates a postscript plot format which includes all vector and raster images.
The ten hard copies supplied were plotted on an HP755 CM Design Jet.
Four individual dxf files (for each 1:100,000 map sheet) were then exported from MicroStation.
They are:

(i) the title surround information (levels 8, 9, 20-24);
(ii) the digital topography (levels 25-56);

(iii) the total field contours (levels 10-13); and
(iv) the flight path (levels 14-16).

Final Deliverables

Final Maps

The maps are presented at a scale of 1:100,000. Flight path and planimetry are presented with the black-line and colour interval contours. Ten copies were delivered; five folded and five rolled.

Digital Data

Final archives of the line and grid data were prepared in the archival formats specified in Appendix B. These archives include:

- postscript plot files of each final map sheet;
- DXF files of flight path, black-line contours, planimetry and titles for each map sheet; and
- TIF files of the colour contours for each map sheet.

Geoterrex has plotted back the digital data, for verification purposes, before submission to the Technical Inspector.

Copies of all data (original and final) will be stored by Geoterrex for four months after the safe delivery of the same data to the G.S.C. Project Leader. During this time, the tapes will not be erased except by explicit written authorization of the Project Leader.

Project Report

Ten copies of this Project Report were delivered.

Chart Records

All chart records are stamped to show the survey number, job numbers, flight line numbers corresponding to those used on the published maps, vertical and horizontal calibrations and/or scales. The air data for each flight line is enclosed in a single labelled envelope. The ground magnetic data for each flight and each station is enclosed in a single envelope. Video cassettes are labelled showing the date and flight number, and are accompanied by a listing relating flight numbers, line numbers and fiducials.

Equipment Log Book

The equipment log book notes all equipment replacements and repairs throughout the survey. It is included as Appendix A.

Levelling Listings

They include the compilation listings and level plots.

Should you have any questions, please do not hesitate to contact us.

Respectfully Submitted

Brian Schacht, P. Geoph.

APPENDIX A

Equipment Log Book

Equipment Log (1995 - 1996)

August 6/95	Tied magnetometer power supply to equipment on the ground (previously floating) to see the effect on the 4th difference.
August 19/95	Changed magnetometer and sensor in stinger. Old magnetometer was holding high current at .8 amps and not dropping to .4 amps when operational. CS-2, S/N 9412011 (now installed).
August 21/95	Reseated boards in DAS.
August 30/95	Clean all connectors on rack.
September 16/95	Installed Omnistar DGPS, S/N 630279 (6800A Omnistar, Version 3.10).
September 18/95	Toshiba laptop installed for running drape profile software.
October 9/95	Cleaned connections to barometric altimeter, RMS compensator and floptical disk drive.
October 21/95	Changed fluxgate magnetometer to Develco 3 axis. Fluxgate magnetometer, model 9202, S/N 1527-487.
October 22/95	Changed AADC (compensator), S/N 9009505.
January 9/96	Checked cables in stinger for continuity and checked sensor for tightness.

APPENDIX B

Digital Archive Format

DIGITAL ARCHIVE FORMAT

All archive files are ASCII, on EXABYTE tapes; record length 80 bytes.

Only the block header contains alphanumeric data.

The data is ordered by incrementing line numbers. The data did not stop in the middle of a flight line.

The survey block will contain the following files:

(i) Line Archive

File No. 1	Line header
File No. 2	Final data for each recorded point as it exists immediately prior to gridding (using appropriate null values)

(ii) Grid Archive

File No. 1	Gridded data used to produce the final contour maps
File No. N	(1 file for each central meridian or UTM zone)

Geographic coordinates in decimal degrees are used for all positional coordinates. The Universal Transverse Mercator projection was used for creating the gridded data. The UTM zone will be the same as that used on the particular topographic maps supplied for the survey area. All longitudes west of Greenwich are represented as negative degrees. Each survey grid origin is a multiple of the grid interval from the Central Meridian and 0° latitude.

Detail Specifications

Line Archive

<u>Block Header (File No. 1)</u>

Record No. 1	Survey block number, number of sheets, GSC project number, Geoterrex project number (Format (A10,I10,2A10,40X))(right justified)
Record No. 2	NTS Map Number (Format (A10,70X))
Record No. 3 to 4	Contain the latitude and longitude in decimal degrees consecutively, of the four map corners. (Corner 1 is the lower left corner, increasing clockwise.) (Format (4E20.10))
Record N + 1	End of file.

Records 2 to 4 would be repeated for each map in the survey block on records No. 5 to Nth.

Individual line segments (File No. 2)

A line header is provided for each line segment. It contains:

- flight number
- line and segment number (e.g., line 1, segment 0=10, line 1, segment 1=11)
- direction code
- traverse/control line code
- start time
- end time
- date of flight as day, month, year (ddmmyy)

(Format (2I10,10X,2I10,2F10.2,I10))

Direction Codes		
	1 = North	Traverse Code = 0
	2 = East	Control Line Code = 1
	3 = South	
	4 = West	

Date records for each recorded point contain the following, in the order listed:

Record #1

NAME	CONTENTS	UNITS	UNITS	NULL VALUE ADDED
TIME	UTC Time	seconds	F10.2	N/A
LAT	Latitude coordinate (NAD 83)	decimal degrees	F10.5	5000
LONG	Longitude coordinate (NAD 83)	decimal degrees	F10.5	5000
MAGLEV	Levelled total field	nT	F10.2	500,000
MAGRAW	Edited raw total field	nT	F10.2	500,000
RALT	Radar altimeter	m	F10.2	50,000
BALT	Barometric altimeter	m	F10.2	50,000
DIURNAL 1	Edited ground magnetics - main base station (Watson Lake)	nT	F10.2	500,000

Record #2

NAME	CONTENTS	UNITS	UNITS	NULL VALUE ADDED
DIURNAL 2	Edited ground magnetics - remote (Fort Nelson)	nT	F10.2	500,000
GPS ALT	Edited GPS altitude (differentially corrected)	m	F10.2	50,000
LAT	Latitude coordinate (NAD27)	decimal degrees	F10.5	5,000
LONG	Longitude coordinate (NAD27)	decimal degrees	F10.5	5,000
SURFACE	Drape Surface	m	F10.2	50,000
MAG BEFORE	Total Field before microlevelling	nT	F10.2	500,000
MAG AFTER	Total Field after microlevelling	nT	F10.2	500,000
EMPTY FIELD				

The end of data for each line is denoted by two zero records in the same format as the data records and followed by blank records to fill the 5040 byte block. The last line on an archive is followed by an END OF FILE after the last complete block. Each new line segment starts with a new 5040 byte block for easier access.

Each field of data is edited and error free.

Grid Archive

The Technical Inspector was consulted prior to archive generation.

For any survey block the number of grid values per row and column is constant for that block (i.e., a full rectangle of gridded data). This infers the following:

(i) As the UTM projection of a block boundary is not a true rectangle, the grid boundary is a rectangle which encloses the four block corners.

(ii) If any grid point cannot be given an interpolated value, then a null value (-9999.000) is assigned to that grid point.

(iii) To ensure exact matching of contoured maps the grid extends by at least five grid points beyond the smallest rectangle which contains the block corners. Each grid has a common origin, to ensure that all grids may be merged back together.

File Contents

Note: Two grids for survey area (2 different central meridians) in order to comply with standard UTM zones.

Header

Record No. 1
- survey block number
- flight altitude
- grid spacing in metres
- number of grids in X direction (columns)
- number of grids in Y direction (rows)
- Central Meridian

(Format 2A10,F10.2,2I10,E20.10,10X)

Record No. 2 to 5 - latitude, longitude, easting, northing of four expended block-surround corners, with 1 corner per record

(Format (4E20.10))

Record No. 6 to 9 - latitude, longitude, easting, northing of four actual grid corners, with 1 corner per record

(Format (4E20.10))

Data

The above is followed by a string of grid values, a column at a time, that is, each column begins a new record:

e.g., WRITE(,)(GRID(IROW,ICOL),IROW=1,NCROWS)
(Format (8F10.3))

All archives were read and a computer evaluation printout is submitted for each archive showing validity. For each line archive, the computer printout shows the line headers, record and block number on the tape and a sample listing of at least the first nine records of each grid archive.