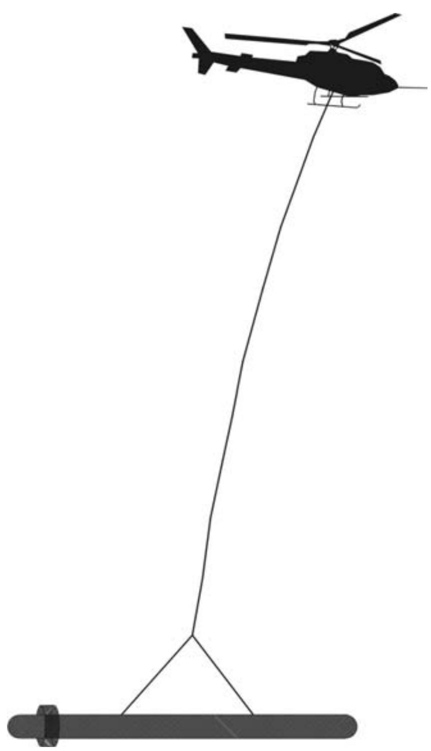
Report #: 03076

Helicopter-borne MAGNETIC SURVEY for the UNITED STATES GEOLOGICAL SURVEY Blanca and Taos Areas



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SUMMARY

This report describes the logistics, data acquisition, processing and presentation of results of a High-Resolution Stinger-Mounted Magnetometer System (hereinafter called "HM1") airborne geophysical survey carried out for the United States Geological Survey, over properties located in Colorado and New Mexico. Total coverage of the survey blocks amounted to 5204.8 km (3234.8 mi). The survey was flown from October 17 to October 31, 2003.

The purpose of the survey was to record airborne geophysical data suited for structural evaluation and identification of lithologic trends over areas of interest to the United States Geological Survey. This was accomplished by using a high-resolution stinger-mounted cesium magnetometer. The information from the sensor was processed to produce data that display the magnetic properties of the survey areas. A GPS electronic navigation system ensured accurate positioning of the geophysical data with respect to the base maps.

The survey data were processed and compiled in the Fugro Airborne Surveys Toronto office. Grid products and digital data were provided in accordance with formats specified in the Survey Agreement.

1. INTRODUCTION

An HM1 magnetic survey was flown for the United States Geological Survey, from October 17 to October 31, 2003, over 2 separate survey blocks located in Colorado (Blanca Area) and New Mexico (Taos Area). The survey areas can be located on reference map sheets NJ13-8 for the Blanca Area, Colorado and NJ13-11 for the Taos Area, New Mexico

Figure 1: HM1 sytem

Survey coverage consisted of 5204.8 km (3234.8 mi), including tie lines. The flight line summary is described in the table below. Tie lines were flown orthogonal to the traverse lines.

Table 1-1

Block	Line Type	Line Direction	Line Spacing
Blanca, CO	Traverse	E-W (90°)	200 meters
	Tie-Lines	N-S (0°)	1000 meters
Taos, NM	Traverse	E-W (90°)	200 meters
	Tie-Lines	N-S (0°)	2000 meters

The survey employed an HM1 magnetometer system. Ancillary equipment consisted of radar and barometric altimeters, video camera, analog and digital recorders, and an electronic navigation system. The instrumentation was installed in a Bell 206B JetRanger helicopter (Registration C-FFUJ) that was provided by National Helicopters. The helicopter flew at an average airspeed of 144 km/h (90 mph) with an average sensor height of 145 meters (475 feet).

2. SURVEY AREA

Bases of operations were established in Alamosa, Colorado, for the Blanca Area, and in Taos, New Mexico for the Taos Area.

Table 2-1 lists the corner coordinates of the survey areas in NAD27, UTM Zone 13, central meridian 105° W.

Table 2-1 - Blanca Area

Nad27 UTM Zone 13

Block	Corners	X-UTM (E)	Y-UTM (N)
03076-1	1	440950	4153860
Blanca Area	2	458637	4153860
	3	463068	4143840
	4	467601	4134298
	5	471191	4126612
	6	472144	4124205
	7	472132	4120600
	8	469528	4118640
	9	455636	4118640
	10	455679	4126680
	11	450701	4134381
	12	450184	4134384
	13	447771	4138004
	14	447808	4143840
	15	440878	4143840

Table 2-2 - Taos Area

Nad27 UTM Zone 13

Block	Corners	X-UTM (E)	Y-UTM (N)
03076-2,3	1	441404	4037926
Taos Area	2	446853	4037891
	3	446894	4044546
	4	449803	4044529
	5	451883	4043038
	6	453061	4040073
	7	452078	4037860
	8	452074	4037121
	9	455198	4034886
	10	455193	4033961
	11	451397	4022889
	12	448610	4019485
	13	441279	4019532

The survey specifications were as follows:

Parameter	Specifications
Sample interval	10 Hz, 4.0 m @ 145 km/hr
Aircraft mean terrain clearance	130-150 m
Mag sensor mean terrain clearance	130-150 m
Average speed	145 km/h
Navigation (guidance)	±5 m, Real-time GPS
Post-survey flight path	±2 m, Differential GPS

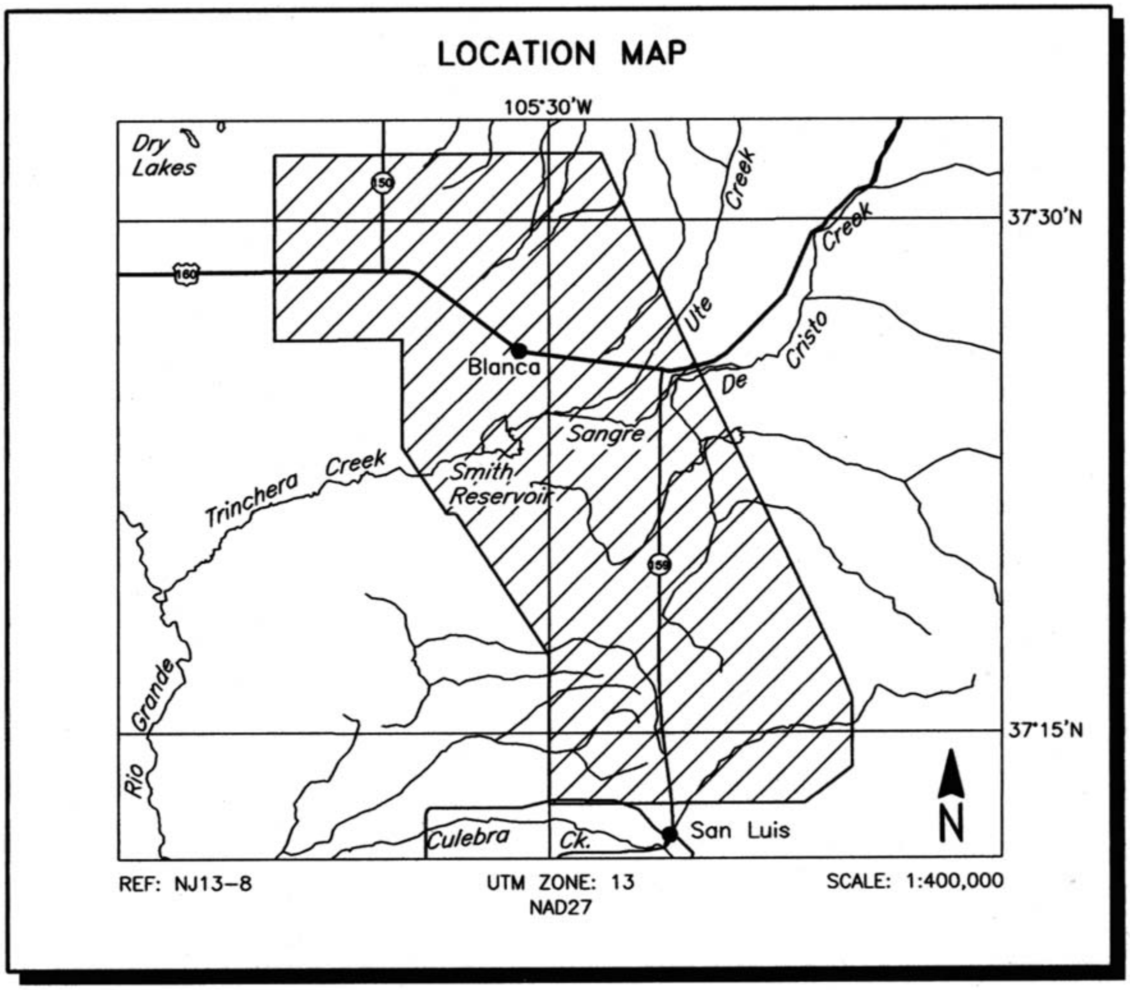

Figure 2
Location Map
Blanca, Colorado
Job # 03076

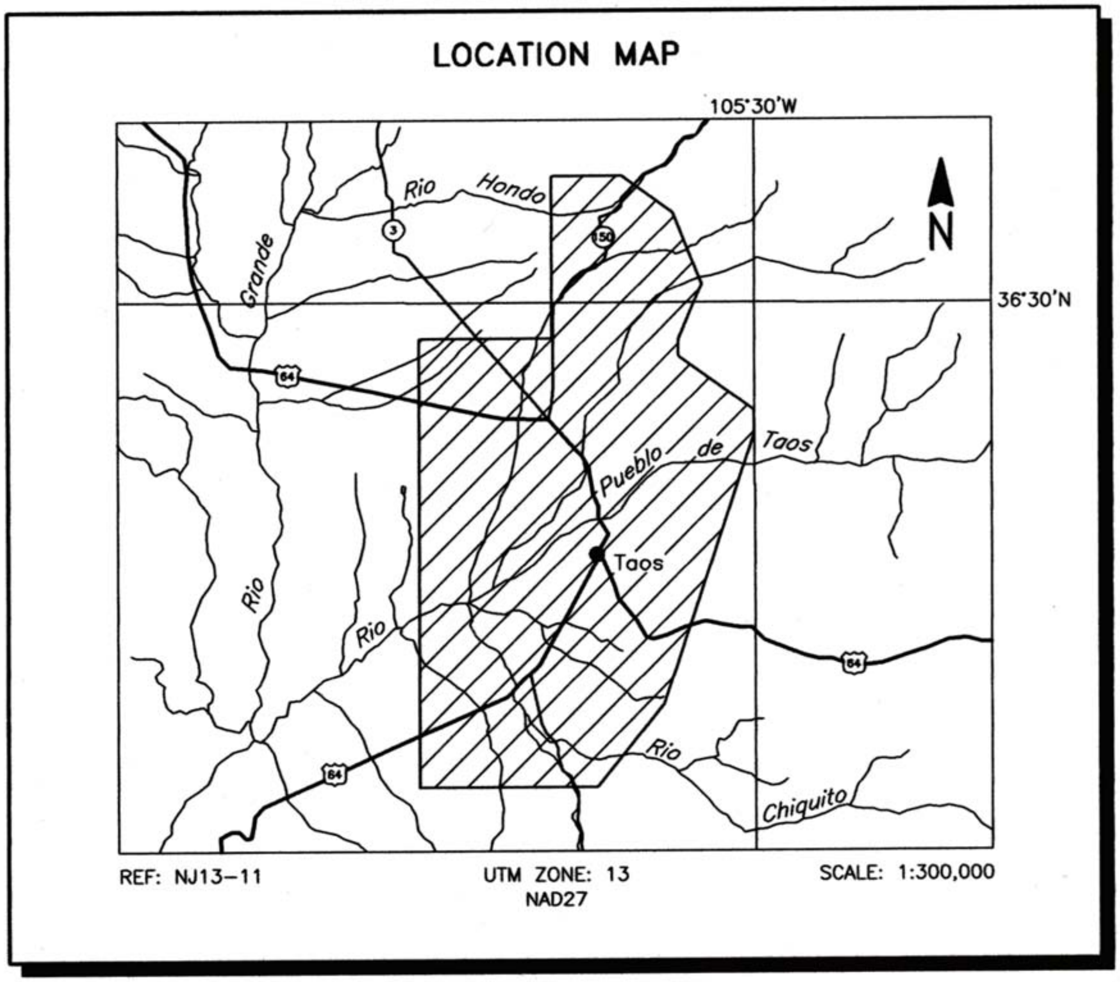

Figure 3
Location Map
Taos, New Mexico
Job # 03076

3. SURVEY EQUIPMENT

This section provides a brief description of the geophysical instruments used to acquire the survey data and the calibration procedures employed. The geophysical equipment was installed in a Bell 206B JetRanger helicopter. This aircraft provides a safe and efficient platform for surveys of this type.

Figure 4: HM1 platform system

Airborne Magnetometer

Model:	Fugro MM2 processor with Geometrics G822 sensor
Type:	Optically pumped cesium vapour

Sensitivity:	0.01 nT
Sample rate:	10 per second

The magnetometer sensor is located in a “stinger”, a rigid boom attached to the front of the helicopter. The helicopter mean terrain clearance is 145 meters.

Magnetic Base Station

Primary

Model:	Fugro CF1 base station with timing provided by integrated GPS	
Sensor type:	Geometrics G822	
Counter specifications:	Accuracy:	±0.1 nT
	Resolution:	0.01 nT
	Sample rate	1 Hz
GPS specifications:	Model:	Marconi Allstar
	Type:	Code and carrier tracking of L1 band, 12-channel, C/A code at 1575.42 MHz
	Sensitivity:	-90 dBm, 1.0 second update
	Accuracy:	Manufacturer’s stated accuracy for differential corrected GPS is 2 meters
Environmental Monitor specifications:	Temperature:	

- Accuracy: ±1.5ºC max
- Resolution: 0.0305ºC
- Sample rate: 1 Hz
- Range: -40ºC to +75ºC

Backup

Model:	GEM Systems GSM-19T
Type:	Digital recording proton precession
Sensitivity:	0.10 nT

Sample rate: 3 second intervals

A digital recorder is operated in conjunction with the base station magnetometer to record the diurnal variations of the earth's magnetic field. The clock of the base station is synchronized with that of the airborne system, using GPS time, to permit subsequent removal of diurnal drift. The Fugro CF1 was the primary magnetic base station. A base station for each survey block was established. The coordinates for each survey block are described in the table below. (Table 3-1)

Table 3-1

ALAMOSA CF1 POSITION – WGS84 LAT/LON		
Latitude	Longitude	Elevation
37°26'49.01640" N	105°51'42.4440" W	2209.9 m
Base Value	52410 nT	
TAOS CF1 POSITION – WGS84 LAT/LON		
Latitude	Longitude	Elevation
36°27'22.6440" N	105°40'44.8284" W	2133.3 m
Base Value	50965 nT	

Magnetic Base Station Locations

Navigation (Global Positioning System)

Airborne Receiver for Real-time Navigation & Guidance

Model: Ashtech Glonass GG24 with PNAV 2100 interface

Type:	SPS (L1 band), 24-channel, C/A code at 1575.42 MHz, S code at 0.5625 MHz, Real-time differential.
Sensitivity:	-132 dBm, 0.5 second update
Accuracy:	Manufacturer's stated accuracy is better than 5 meters real-time
Antenna:	Mounted on tail of aircraft

<u>Airborne Receiver for Flight Path Recovery</u>

Model:	NovAtel MiLLennium
Type:	Code and carrier tracking of L1 band, 24-channel, dual frequency C/A code at 1575.2 MHz, and L2 P-code 1227 MHz.
Sample rate:	0.5 second update.
Accuracy:	Manufacturer's stated accuracy for differential corrected GPS is better than 1 meter.
Antenna:	Mounted on the magnetometer stinger.

<u>Primary Base Station for Post-Survey Differential Correction</u>

Model:	Ashtech Z-Surveyor
Type:	Code and carrier tracking of L1 band, 12-channel, dual frequency C/A code at 1575.2 MHz, and L2 P-code 1227 MHz
Sample rate:	1.0 second update
Accuracy:	Manufacturer's stated accuracy for differential corrected GPS is better than 1 meter

<u>Secondary GPS Base Station</u>

Model:	Marconi Allstar OEM, CMT-1200
Type:	Code and carrier tracking of L1 band, 12-channel, C/A code at 1575.42 MHz

Sensitivity: -90 dBm, 1.0 second update

Accuracy: Manufacturer's stated accuracy for differential corrected GPS is 2 meters.

The Ashtech GG24 is a line of sight, satellite navigation system that utilizes time-coded signals from at least four of forty-eight available satellites. Both Russian GLONASS and American NAVSTAR satellite constellations are used to calculate the position and to provide real time guidance to the helicopter. For flight path processing a NovAtel MiLLennium was used as the mobile receiver. An Ashtech Z-Surveyor was used as the primary base station receiver. The mobile and base station raw XYZ data were recorded, thereby permitting post-survey differential corrections for theoretical accuracies of better than 2 meters. A Marconi Allstar GPS unit, part of the CF-1, was used as a secondary (back-up) base station.

For the survey blocks a primary GPS station location was located for each area as described in Table 3.2. The GPS records data relative to the WGS84 ellipsoid, which is the basis of the revised North American Datum (NAD83). Conversion software is used to transform the WGS84 coordinates to the NAD27 UTM system displayed on the maps.

Table 3-2

ALAMOSA GPS POSITION – WGS84 LAT/LON		
Latitude	Longitude	Elevation
37°26'29.03106" N	105°51'57.40060" W	2290.08 m
TAOS GPS POSITION – WGS84 LAT/LON		
Latitude	Northing	Elevation
36°27'22.74672" N	105°40'44.86794" W	2151.19 m

GPS Base Station Locations

Radar Altimeter

Manufacturer:	Terra
Model:	TRA3000
Type:	Short pulse modulation, 4.3 GHz
Sensitivity:	0.3 m
Sample rate:	2 per second

The radar altimeter measures the vertical distance between the helicopter and the ground.

Temperature Sensor

Model:	DIGHEM D 1300
Type:	AD592AN high-impedance remote temperature sensors
Sensitivity:	Temperature: 100 mV/°C or 10 mV/°C (selectable)
Sample rate:	10 per second

The D1300 circuit is used in conjunction with the temperature sensor, to monitor air temperature.

Digital Data Acquisition System

Manufacturer:	Fugro
Model:	PDAS

Recorder: Compact flash card (PCMCIA)

The stored data are downloaded to the field workstation PC at the survey base, for verification, backup and preparation of in-field products.

Video Flight Path Recording System

Type:	Sony DXC-101
Recorder:	Panasonic AG-720
Format:	NTSC (VHS)

Fiducial numbers are recorded continuously and are displayed on the margin of each image. This procedure ensures accurate correlation of data with respect to visible features on the ground.

Magnetic Compensation

The HM1 system was calibrated using a magnetic compensation procedure described in *APPENDIX D*. The general purpose for the compensation is to establish calibration values, which are used to remove the effects of the helicopter motion “seen” by the magnetometer sensor. The procedure is required because of the close proximity of the magnetometer sensor to the helicopter.

Compensation Flight

The compensation flight result is the sum of each maneuver (described in Appendix D) for each cardinal direction. The compensation result for the flight flown on October 17, 2003, was 1.66. The results are displayed below.

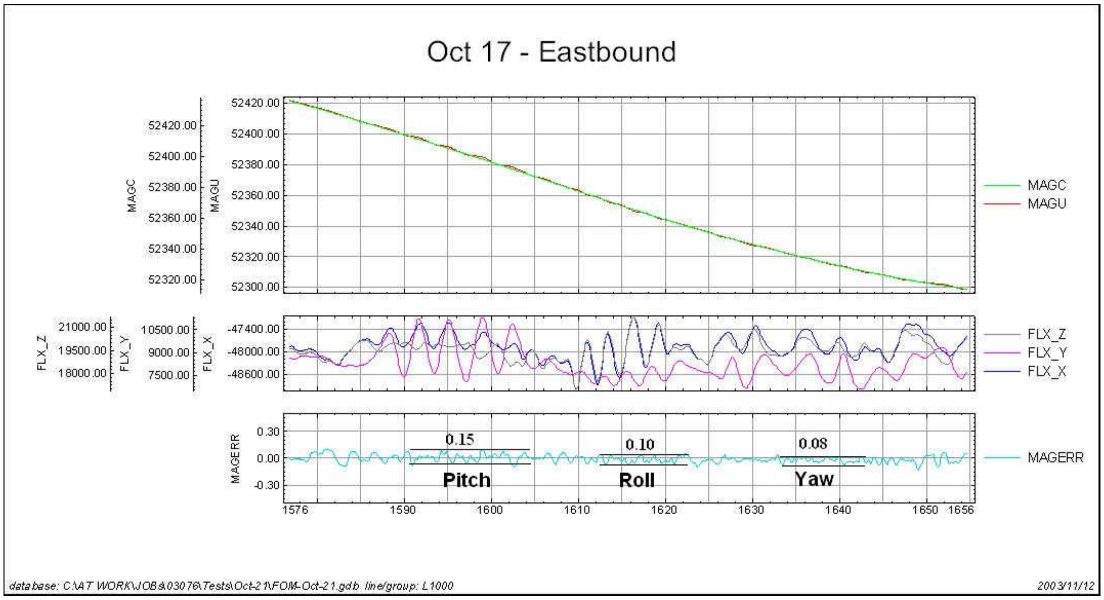

Figure 5 - Eastbound Compensation (0.33)

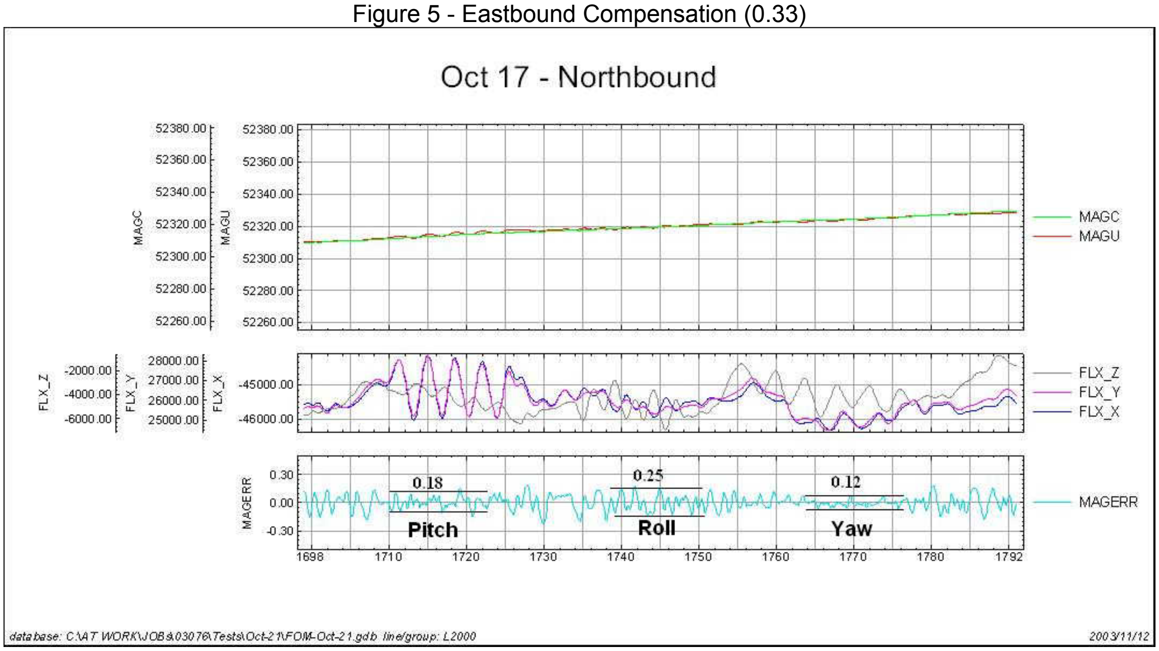

Figure 6 - Northbound Compensation (0.55)

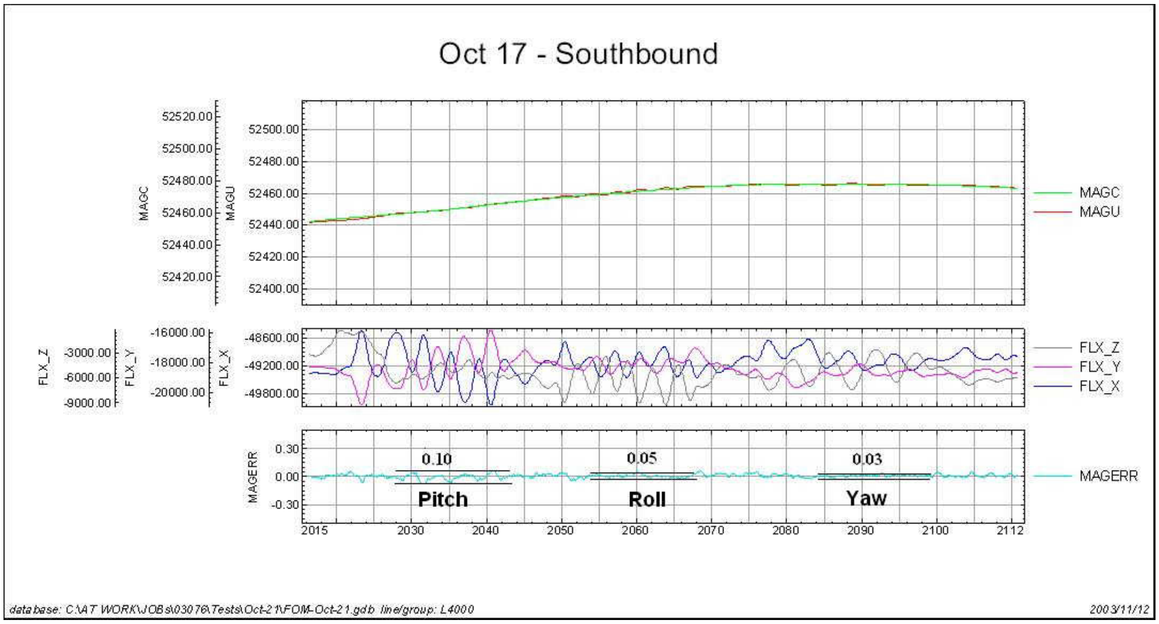

Figure 7 - Southbound Compensation (0.18)

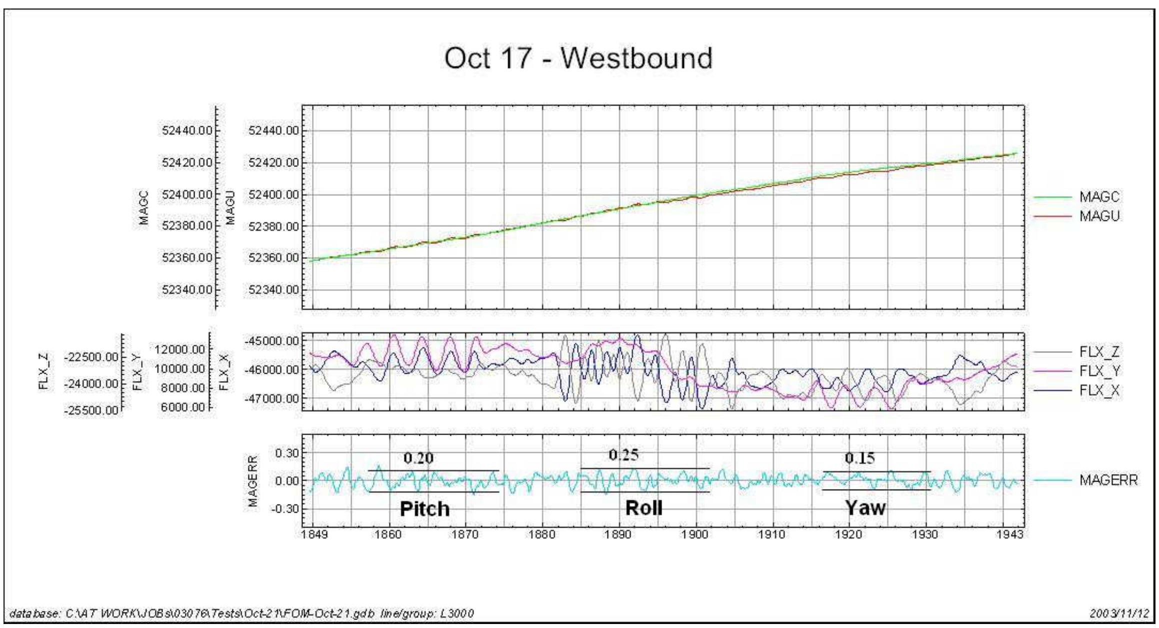

Figure 8 - Westbound Compensation (0.60)

The summary of the results is calculated as follows.

Eastbound Compensation:	0.33
Northbound Compensation:	0.55
Southbound Compensation:	0.18
Westbound Compensation:	0.60
Compensaton Result (FOM value):	1.66

A second calibration flight was performed near the end of the survey to verify the system. It was flown on October 27, 2003, with a compensation result of 1.58.

The same procedures of this flight were followed as described for the October 17 compensation flight.

4. QUALITY CONTROL

Digital data for each flight were transferred to the field workstation, in order to verify data quality and completeness. A database was created and updated using Geosoft Oasis Montaj and proprietary Fugro Atlas software. This allowed the field personnel to calculate, display and verify both the positional (flight path) and geophysical data on a screen or printer. Records were examined as a preliminary assessment of the data acquired for each flight.

In-field processing of Fugro survey data consists of differential corrections to the airborne GPS data, magnetic spike rejection and filtering of all geophysical and ancillary data, verification of flight videos, diurnal correction, and preliminary leveling of magnetic data.

All data, including base station records, were checked on a daily basis, to ensure compliance with the survey contract specifications. Reflights were required if any of the following specifications were not met.

Navigation - Positional (x,y) accuracy of better than 5 m, with a CEP (circular error of probability) of 95%.

Flight Path - No lines to exceed ±50 meter departure from nominal line spacing over a continuous distance of more than 3 km, except for reasons of safety.

Clearance - Mean terrain sensor clearance of 140 m, ±10 m over a distance of 1 km, except where precluded by safety considerations, e.g., restricted or populated areas, severe topography, obstructions, tree canopy, aerodynamic limitations, etc.

Airborne Mag Aerodynamic magnetometer noise envelope not to exceed ±0.1 nT. Less than 3 nT variation for pitch and roll. Heading error less than 1 nT.

Base Mag - Diurnal variations not to exceed 5 nT over a linear chord of 5 minutes.

5. DATA PROCESSING

Flight Path Recovery

Both the base and mobile GPS units simultaneously record the raw range data from at least four satellites. The geographic positions of both units, relative to the model ellipsoid, are calculated from this information. Differential corrections, which are obtained from the base station, are applied to the mobile unit data to provide a post-flight track of the aircraft, accurate to within 2 meters. Speed checks of the flight path are also carried out to determine if there are any spikes or gaps in the data.

The corrected WGS84 latitude/longitude coordinates are transformed to the NAD27 UTM coordinate system used on the final maps. Images or plots are then created to provide a visual check of the flight path.

Total Magnetic Field

The raw magnetic channel was manually despiked (MAGR) using a fourth difference channel as a reference. A lag of 0.5 seconds (5.0 scans) was then applied to the despiked magnetic channel. Lag was determined by using linear features and sharp anomalies to visually line up the data. Diurnal correction was then applied to produce a despiked, lagged and diurnally corrected channel (MAGCD_LAG). The IGRF was then removed from the total magnetic field data yielding a residual magnetic field channel (MAG_IGRF) to be leveled. A zero order correction (dc adjustment) was applied to the traverse and tie lines (MAGADJ). Review of the DC adjusted magnetics, allowed for verification of the tie line and traverse line levels before proceeding to leveling network adjustments. Tie line leveling was applied (a second order fit) to level the traverse lines (MAGADJ_MAN). The new tie line leveled magnetic channel was gridded and shadowed for quality inspection. From inspection of the shadow results, manual adjustments were applied and then subjected to a microleveling filter. These final adjustments resulted in the final residual magnetic intensity (MAG_FIN).

IGRF was computed on a point-by-point basis using the final GPS Z channel as height above sea level and a year 2000 table of coefficients. October 2003 was the calculation date.

Digital Elevation

The helicopter altimeter (aircraft to ground clearance) was filtered with a 15 pt Median and Hanning to remove spikes and system noise. The filtered helicopter altimeter is subtracted from the differentially corrected and de-spiked GPS-Z values to produce profiles of the height above the ellipsoid along the survey lines. These values are gridded to produce contour maps showing approximate elevations within the survey area. Any line-to-line discrepancies are manually removed. After the manual corrections are applied, the digital terrain data are filtered with a microleveling algorithm. The final digital elevation profile is calculated by the equation shown below.

DEMZ_FIN = Z_FIN (final GPS Z) – ALT_FIN (final heli. altimeter)

The accuracy of the elevation calculation is directly dependent on the accuracy of the two input parameters, helicopter altimeter and GPS-Z. The helicopter altimeter value may be erroneous in areas of heavy tree cover, where the altimeter reflects the distance to the tree canopy rather than the ground. The GPS-Z value is primarily dependent on the number of available satellites. Although post-processing of GPS data will yield X and Y accuracies in the order of 1-2 meters, the accuracy of the Z value is usually much less, sometimes in the ±10 meter range. Further inaccuracies may be introduced during the interpolation and gridding process.

Because of the inherent inaccuracies of this method, no guarantee is made or implied that the information displayed is a true representation of the height above sea level. Although this product may be of some use as a general reference, THIS PRODUCT MUST NOT BE USED FOR NAVIGATION PURPOSES.

Contour and Gridding Procedure

The geophysical data are interpolated onto a regular grid using a modified Akima spline technique. The resulting grid is suitable for image processing and generation of contour maps. The grid cell size is 20% of the line interval.

APPENDIX C

ARCHIVE DESCRIPTION

This CD-ROM contains final data archives of an airborne survey conducted by Fugro Airborne Surveys on behalf of the United States Geological Survey in Colorado and New Mexico from October 17 to October 31, 2003.

Fugro Job #: 03076

The archives contain 3 directories.

1. XYZ: Geosoft ASCII X.Y Z format archive.
    1. Blanca_final.xyz
    2. Taos_final.xyz

2. Grids: Grids in Geosoft format for the following parameters:
    1. Residual Magnetic Field
    2. Digital Elevation Model
    3. Radar Altimeter of the helicopter

3. Report: Report in Adobe PDF format.

<u>Projection Description</u>:

Datum:	**WGS84**
Ellipsoid:	GRS80
Projection:	UTM (Zone: 13 N)
Central Meridian:	105° W
False Northing:	0
False Easting:	500000
Scale Factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Datum Shifts:	DX: 0 DY: 0 DZ: 0

Datum:	**NAD27**
Ellipsoid:	GRS80
Projection:	UTM (Zone: 13 N)
Central Meridian:	105° W
False Northing:	0
False Easting:	500000
Scale Factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Datum Shifts:	DX: 8 DY: -159 DZ: -175

DATABASE: SURVEY ARCHIVE LIST

```
====================================================
 NUMBER OF DATABASE CHANNELS: 26
====================================================
    1 - LINE         5, 0                 Flight Line ID
    2 - DIR          3, 0                 Flight line direction
    3 - FLT          3, 0                 Flight number
    4 - X_84F       11, 2                 FINAL UTM X- GRS80 (WGS84 - UTM Zone 13 N) (m)
    5 - Y_84F       12, 2                 FINAL UTM Y- GRS80 (WGS84 - UTM Zone 13 N) (m)
    6 - X_27F       11, 2                 FINAL UTM X- GRS80 (NAD27 - UTM Zone 13 N) (m)
    7 - Y_27F       12, 2                 FINAL UTM Y- GRS80 (NAD27 - UTM Zone 13 N) (m)
    8 - LAT_84F     14, 7                 LATITUDE GPS WGS84 (deg.d)
    9 - LON_84F     12, 7                 LONGITUDE GPS WGS84 (deg.d)
   10 - LAT_27F     14, 7                 LATITUDE GPS NAD27 (deg.d)
   11 - LON_27F     12, 7                 LONGITUDE GPS NAD27 (deg.d)
   12 - FIDUCIAL    10, 1                 FIDUCIAL COUNTER
   13 - DATE        11, 1                 Flight date (YYYY/MM/DD)
   14 - UTC         10, 1                 UTC TIME
   15 - ALT_FIN     10, 1                 HELICOPTER RADAR ALTIMETER (m)
   16 - Z_FIN       10, 1                 GPS ALTITUDE (m)
   17 - DEMZ_FIN    10, 1                 FINAL DIGITAL ELEVATION MODEL (Z_FIN-RALT_ML) (m)
   18 - MAGR        10, 2                 RAW TOTAL FIELD Magnetic Intensity despiked (nT)
   19 - MAGCD_LAG   10, 2                 Diurnal corrected and lagged Total Magnetic Intensity (nT)
   20 - MAG_IGRF    10, 2                 RESIDUAL Magnetic Intensity (IGRF removed) (nT)
   21 - MAGADJ      10, 2                 RESIDUAL Magnetic Intensity (DC-adjusted)  (nT)
   22 - MAGADJ_MAN  10, 2                 RESIDUAL Magnetic Intensity (tie-line levelled) (nT)
   23 - MAG_FIN     10, 2                 FINAL RESIDUAL Magnetic Intensity (nT)
   24 - DIURNAL     10, 2                 Diurnal (nT)
   25 - IGRF        10, 2                 IGRF (nT)
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