TECHNICAL REPORT ON AN AIRBORNE GEOPHYSICAL SURVEY OF CENTRAL OKLAHOMA

Contract No. G17PC00038

FOR THE

UNITED STATES GEOLOGICAL SURVEY

BY

GOLDAK AIRBORNE SURVEYS

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1 INTRODUCTION

This report describes an airborne geophysical survey conducted in over three distinct areas in Central and Southern Oklahoma. This high sensitivity aeromagnetic surveys were carried out by Goldak Airborne Surveys (Goldak) on behalf of the United States Geological Survey (USGS) between August 11th and October 28th, 2017.

Aircraft equipment operated included a cesium vapour magnetometer, a GPS real-time and post-corrected differential positioning system, as well as radar and barometric altimeters. All data were recorded digitally in GEDAS binary file format.

Reference ground equipment included a GEM Systems GSM-19W Overhauser magnetometer and a Novatel 12 channel GPS base station which was set up at the base of operations for differential post-flight corrections.

Fifty one flights (including test and calibration sorties) were required to complete the survey. A total of 44,551 line kilometres of high resolution magnetic was collected, processed and compiled.

The largest of the blocks, Area 123, was flown with traverse lines spaced at 400 metres with control lines flown at a separation of 4 000 metres. Area 4 was flown with a traverse line spacing of 1 000 metre sand control lines spaced at 10 000 metres. Area 5 used and 800 meter traverse line spacing and an 8 000 metre control line spacing. Nominal terrain clearance was specified at 120 metres above ground for all blocks however regulations pertaining to flight over built up areas required the altitude to be raise in many instances. Altus, OK was used as the base of operations for the first part of the survey. Operations were moved to Chickasha, OK for the latter part of the project.

All installations and equipment specifications are described in more detail in Section 4 of this report. Daily operational logs were kept and are included as Appendix B of this report.

2 SURVEY AREA LOCATION

The survey was comprised of three blocks in Central and Southern Oklahoma.

In relation to the state capital, Oklahoma City, Area 123 was centred 150 km SW at approximately 34°47N, 98°48W. Area 4 was centred 150 km NW at about 36°33'N, 98°41'W while Area 5 was centred 75 km to the NE of at roughly 36°53N, 96°56'W.

The western part of Area 123 extends into the state of Texas. The original extents of Area 123 had to be altered as they overlapped Ft. Sill restricted airspace. Officials at Ft. Sill had initially indicated we could be accommodated but permission to enter the restricted space was not granted in a suitable time frame.

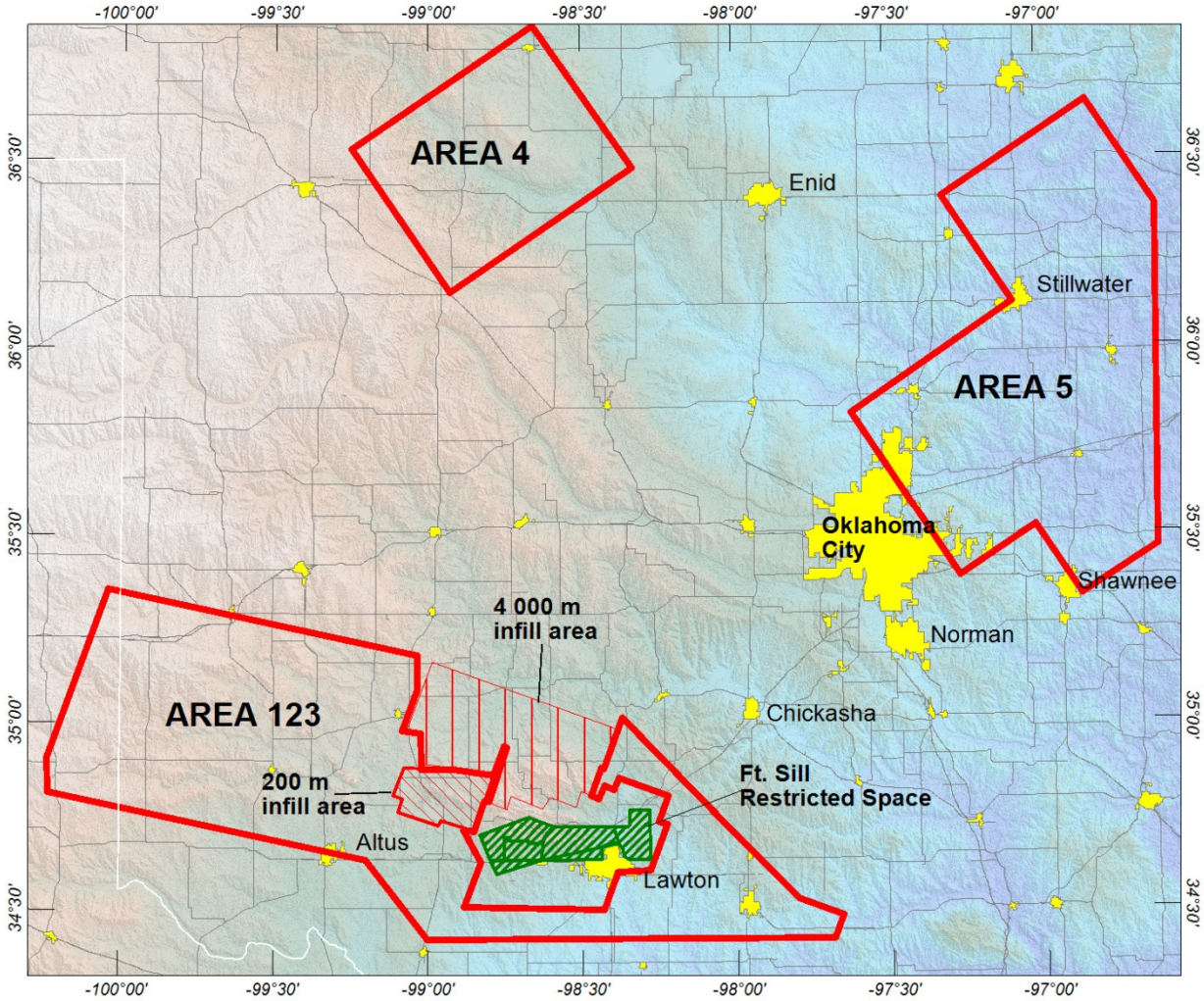

Figure 1 - Location of the Central Oklahoma Survey Blocks

The coordinates of each survey area are posted in Appendix A.

3 CONTRACT SPECIFICATIONS

3.1 Line Spacing

3.1.1 Block 123

Traverse Lines:

- bearing - N 20°E UTM
- spacing - 400 metres, with 200m infill

Control Lines:

- bearing - N 110°W UTM
- nominal spacing – 4 000 metres

3.1.2 Block 4

Traverse Lines:

- bearing - N 146°E UTM
- spacing – 1 000 metres

Control Lines:

- bearing - N 236°W UTM
- nominal spacing – 10 000 metres

3.1.3 Block 5

Traverse Lines:

- bearing - N 146°E UTM
- spacing – 800 metres

Control Lines:

- bearing - N 236°W UTM
- nominal spacing – 8 000 metres

3.2 Altitude

Altitude control was accomplished via a smooth drape constructed using STRM elevation data.

Target nominal altitude: 120 m NTC (nominal terrain clearance)

Actual Mean terrain clearances:

Area 123: 138 m
Area 4: 140 m
Area 5: 178 m

Tolerance: a maximum 30 m difference between traverse lines and control lines. To accomplish this, actual height deviations from the drape surface were not to exceed an envelope of +/- 15 metres at all times.

3.3 Diurnal Specifications

The diurnal tolerances were as follows:

- Monotonic changes in the magnetic field of 5 nT in any five-minute period.
- Pulsations having periods of 5 minutes or less shall not exceed 2 nT.
- Pulsations having periods between 5 and 10 minutes shall not exceed 4 nT.
- Pulsations having periods between 10 and 20 minutes shall not exceed 8 nT.

3.4 Magnetic Noise

The magnetic noise was not to exceed 0.1 nT in the 4th digital difference.

All data was fully examined in the field and home office and was deemed to have met the above specifications.

4 AIRCRAFT AND EQUIPMENT

4.1 Aircraft

Type:.....Piper PA-31 Navajo with VG and LR Fuel Kit
Registration: .....& C-GJBB
Engine hours:.....C-GJBB (1700 hrs to TBO, approved on-condition)
.....C-GJBG (1100 hrs to TBO, approved on-condition)
Cruise Range:.....1500 km
Survey Duration:6.5 hours plus reserve

Max Climb Gradient:.....800 ft/NM
Max Descent Gradient: .....1000 ft/NM
Cruising Speed: .....140 knots
Aviation Fuel:.....100 LL aviation gasoline
Fuel Consumption: .....200 pounds per hour total
Oil Consumption.....0.2 liters per hour total
Long Range Comm:.....Iridium Sat Phone, SPOT

ELT Frequency .....121.5 Mhz, 406 MHz
Tail Stinger: .....4 meter composite
Wingtip Pods: .....1 meter composite
FOM:.....0.8 nT typical

A single Piper PA-31 Navajo, registration C-GJBB, owned and operated by Goldak Airborne Surveys, was used on this survey. The aircraft magnetometers are installed in the 3-meter stinger attached to the rear fuselage and in the 1-metre composite pods attached to each wing-tip. The attitude sensing fluxgate magnetometer is positioned at the midpoint of the stinger. The three magnetometers form a two-axis gradiometer.

The aircraft has been extensively modified, both mechanically and electrically, to minimize the effects of maneuvering on the measured magnetic field. This aircraft has typical a Figure of Merit result of less than 0.7 nT as measured to Geological Survey of Canada (GSC) specification.

Figure 2 - Aircraft C-GJBB at Altus

4.2 Airborne Systems

4.2.1 Data Acquisition System

Manufacturer:	Goldak Exploration Technology Ltd.
Type and Model Number:	GEDAS
Sampling Rate:	10 Hz
Data Format:	GEDAS binary

All magnetic and positioning data are processed and recorded digitally by our GEDAS system. The GEDAS is an industrial rack-mount Intel Pentium based PC computer with multiple hard-drives, IO ports and ADAC devices.

The GEDAS system records GNSS navigation records at 1Hz. Magnetic, radar altimeter and barometric altimeter data are recorded at 10 Hz. All data is tightly synchronized to GPS time with an accuracy of ± 1 millisecond. Each data packet, on arrival to the data system is stamped with a system time with a resolution of 1 millisecond. Data files are organized on a flight-by-flight basis in a proprietary binary format. The data can then imported directly into Geosoft® via a custom import routine.

4.2.2 Magnetometers and Compensation

Aircraft Magnetometers:

Manufacturer:	Geometrics
Type and Model Number:	Cesium G-822A
Range in nT:	20,000 to 90,000
Sensitivity in nT:	0.005
Sampling Rate:	10 Hz

Real-time Magnetic Compensator:

Manufacturer:	RMS Instruments
Type and Model Number:	AADCII
Range in nT:	20,000 to 100,000
Resolution in nT:	0.001
Sampling Rate:	20Hz

The airborne magnetometers installed are a matched set of Geometrics G-822A optically pumped cesium vapour types with sensitivity of 0.005 nT. The magnetometer's Larmor signal is decoupled and counted by a RMS Instruments AADCII compensator, and data are produced at a rate of 10 Hz with a resolution of 0.001 nT. The data bandwidth is from 0 to 0.9 Hz with an internal noise level of less than 0.002 nT.

Compensation mathematically "corrects" the magnetic data for noise due to aircraft motion and heading. Prior to the survey, the aircraft is taken to an area of low magnetic gradient at a high altitude (7000' AGL +) and put through a series of rolls, pitches and yaws on each of the survey's cardinal headings. The data collected from these maneuvers can then be used to form a model of the aircraft's magnetic characteristics without the near influence of the local geology.

The remaining magnetic distortion is quantified by a term known as the Figure of Merit, or FOM. The Geological Survey of Canada uses a figure of merit of 1.5 or less as standard survey criteria.

Two compensation flights pertinent to data collected were completed over the course of the survey. The results of these flights are posted in Appendix A.

4.2.3 GNSS Positioning and Navigation

Navigation System:

Manufacturer	Goldak Exploration Technology Ltd.
Type and Model Number	GENAV
Displays	10” Color LCD data display
	3D Autodrape LCD pilot display

GNSS Receiver:

Manufacturer	Novatel
Type and Model Number:	OEMV dual-frequency ProPakV3 (x1)
System Resolution:	<1 meter
Overall accuracy:	3 m in real-time, <1m post-corrected
Number Channels:	120
Signal Tracking:	GPS L1, L2, L2C, L5
	GLONASS L1, L2
	Galileo E1, E5

The GNSS receiver in the survey aircraft was a GPS and GLONASS capable Novatel OEMV ProPakV3 120 channel dual-frequency differential unit that communicates directly with the GEDAS system. This unit is used for navigation purposes and also logs data for post-flight differential corrections.

GNSS signals can be affected by atmospheric and ionospheric effects which typically reduce the accuracy of the non-differential positioning to approximately 10 metres RMS. If a suitable stationary GPS receiver, on a known or assumed position, is used to record the apparent errors in the satellite range data, those errors can be used to correct the moving receiver in the aircraft to an accuracy of 1 meter RMS. This compensation process is called differential correction and can be applied to the moving receiver in real time for higher dynamic accuracy, or applied later to find out where the aircraft was with high accuracy. These are called real-time and post-corrected differential positioning respectively.

4.2.4 Radar Altimeters

Radar Altimeter 1:

Manufacturer	Thompson
Type and Model Number:	CFS 530A
Range:	0-8000 feet
Resolution:	1 meter
Accuracy:	2%

Radar Altimeter 2:

Manufacturer	Terra
Type and Model Number:	TRA3000 – TRI40
Range:	40-2500 feet
Resolution:	3 metres
Accuracy:	5-7%

4.2.5 Barometric Altimeter

Manufacturer:	Setra
Type and Model Number:	270
Range:	-1000 to 10,000 feet
Resolution:	1 meter

4.3 Ground Systems

4.3.1 Magnetic Base Station

Base Station Magnetometer:

Manufacturer:	GEM Systems
Type and Model Number:	Overhauser GSM-19W
Range in nT:	20,000 to 120,000
Sensitivity in nT:	0.01
Sampling Rate:	1 Hz (5 Hz maximum)

Base Station Data Loggers:

Manufacturer:	Acumen
Type and Model Number:	Data Bridge SDR-CF Serial Data Recorder
Media Type:	Compact Flash

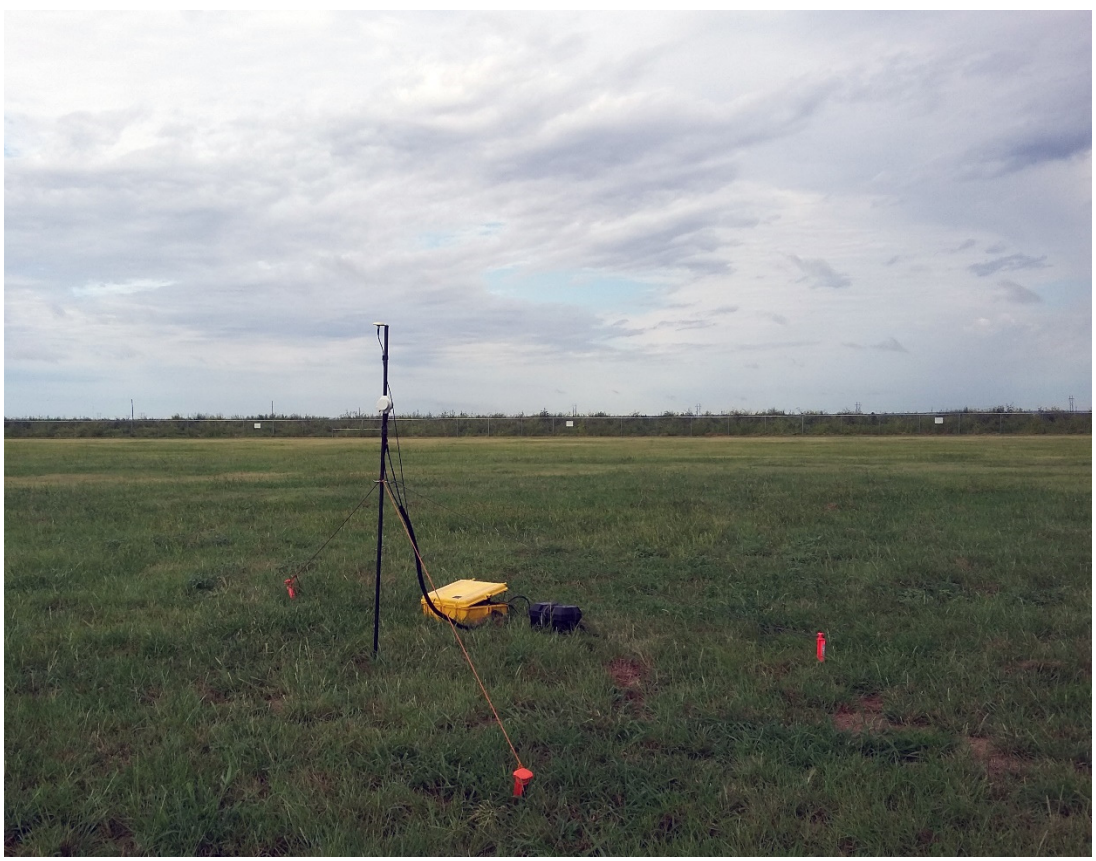

Figure 3 - Base Magnetometer Installation at Altus Airport

A magnetic base station using a GEM Systems GSM19W Overhauser type proton precession magnetometer with GPS time base was set up at the base of operations. The setup was configured to log data both internally and externally to a compact flash card using an Acumen DataBridge SDR serial data recorder. The base station in Altus was set up on the west side of the airfield, 190 m west of the runway. The Base station in Chickasha was also set up on the airfield, on the east side of the runway, 300 m from the apron.

Installation Location	Latitude	Longitude	Reference Value	Flight Range
Altus	34° 41' 51.9"N	99° 20' 26.6"W	49615nT	1 - 36
Chickasha	35° 05' 42.8"N	97° 57' 52.7"W	50265nT	37 - 51

Table 1 - Base Magnetometer Stations

4.3.2 GNSS Base Station

Base GNSS Reciever:

Manufacturer	Novatel
Type and Model Number:	OEMV dual-frequency ProPakV3 (x1)
System Resolution:	<1 meter
Overall accuracy:	3 m in real-time, <1m post-corrected
Number Channels:	120
Signal Tracking:	GPS L1, L2, L2C, L5

The base station receiver unit, like the airborne units, was a Novatel OEMV ProPakV3 whose data were logged by a battery-powered, industrial portable computer. A survey-grade GNSS base antenna designed to minimize multi-path errors was set up on the roof of the Friendship Inn in Altus for flights 1 to 36 and on the roof of the Maverick Inn in Chickasha from flights 37. The precise position of the antenna was determined by collecting 9 hours of data then submitting the data to the NRCan's online Precise Point Positioning (PPP) service. The following WGS84 coordinate was delivered:

Longitude	-99° 19 58.3355
Latitude	34° 39 36.6274
Elevation (MSL)	410.146 m
Flight range	1 - 36

Table 2 - Base GNSS Position Altus

Longitude	-97° 55' 59.2463
Latitude	35° 01' 18.6143
Elevation (MSL)	323.649
Flight range	37 - 51

Table 3 - Base GNSS Position Chickasha

4.4 Field Office Systems

4.4.1 Field Data Verification, Logging and Plotting

Processing Computer:

Manufacturer:	Lenovo
Type and Model Number:	ThinkCentre / Intel i5 3.4 GHz

Data Logging Computers:

Manufacturer:	Lenovo
Type and Model Number:	ThinkPad / Intel i5 3.4 GHz

Plotters and Printers:

Manufacturer:	Brother
Type and Model Number:	HL-2270

Data backup:

Manufacturer:	Western Digital
Type and Model Number:	1.5 TB external HDD

4.4.2 Software

Manufacturer:	Geosoft®
Function:	Geophysical data processing
Type and Model Number:	Oasis Montaj v 7.3

Manufacturer:	Waypoint Consulting
Function:	GPS post-processing
Type and Model Number:	GrafNav v 8.50

5 PERSONNEL

The following Goldak personnel were involved in the Oklahoma project:

Company President – Ben Goldak
Pilot – Jay Mathieson
Co-Pilot/ Instrument Operator – Dustin Biesenthal
Field Manager/ QC – Bill Heath
Flight Block Design – Bill Heath, Glen Carson
Final Data Processing – Bill Heath
Data Processing Manager – Glen Carson
Logistics – Brenda Doherty, Glen Carson, Bill Heath
Aircraft Maintenance – Daniel Leppington

Table 4 - Project Personnel

6 DATA PROCESSING

6.1 Positioning Data and Altitude Data

Processing of the positioning data takes place in the field and is performed on a post-flight basis. The following procedures are included in positioning and altitude data processing:

1. The raw airborne GPS data are corrected using the corresponding GPS base station data and NovAtel® Inc.'s Waypoint® GrafNav® GNSS Post-Processing software suite.
2. The corrected GPS World Geodetic System 1984 (WGS84) longitude, latitude and altitude are merged into a Geosoft® database with aircraft flight data and re-projected to the local UTM Zone 14 WGS84 datum. Velocity is then calculated from the corrected positions. Corrected UTM co-ordinates are trimmed to online.
3. The primary radar altimeter data is lagged by 0.9 seconds and the secondary radar altimeter data is lagged by 3.0 seconds.
4. The digital elevation model is calculated by subtracting the radar altimeter data from the GPS altitude data.
5. Quality-control procedures described in section 7.2 are performed.

6.2 Magnetic Data

6.2.1 Initial Field Processing

Processing of the magnetic data begins in the field where the raw magnetic, positioning and altitude data from the aircraft acquisition systems is first imported into a Geosoft® Oasis montaj™ database on a line basis. The magnetic base station data, logged during the corresponding flight time, were then merged with the flight data for display and quality control checks.

1. A system latency correction, determined from the pre-survey lag test of 0.4 seconds for the tail magnetometer data and 0.3 seconds for the wing-tip magnetometer data, is then applied.
2. A diurnal correction derived from the local magnetic base station data is applied to account for temporal variations in the total magnetic field.
3. The raw, measured magnetic gradients are normalized using the known aircraft sensor separations and aircraft direction to give consistently signed gradient values in units of nT/m. A correction matrix, derived from the attitude data, is then applied scaling them to provide true longitudinal and transverse gradient values parallel to and perpendicular to the ideal line direction.
4. Quality-control procedures described in section 7.2 are performed.

6.2.2 Control-Line Levelling

The intention of control-line levelling is to apply a smoothly-varying function to the measured data, which results in nearly identical values at the intersections of traverse and control lines. The most significant component of the correction is to accommodate the diurnal variation of the magnetic field. Other sources of error are altitude errors, GPS positioning errors and system drift.

Levelling of the total field data consists of the following steps:

1. Calculation of the positions of the survey-line–control-line intersection points and the extraction of mismatch values of the magnetic data between the line and control lines at these points.
2. An iterative application of corrections, based of best-fit, first-order linear trends of mismatch values (with outliers removed), on the traverse and control lines until the resulting corrections approach zero.
3. An iterative application of long-wavelength corrections on traverse and control lines determined by applying median and low-pass filters to the remaining intersection mismatches (with outliers removed) and then using Akima spline interpolation between the now-filtered intersection mismatch values. This enhances and isolates correction "features" that span several intersections. The lengths of the filters are based on the traverse-line–control-line intersection separations. In this case, the initial filter lengths spanned 10 control-line intersections on survey lines and 50 survey-line intersections on control lines. The number of intersections spanned is reduced in increments to an appropriate minimum until the correction approaches zero.
4. Calculation of the first vertical derivative from the gridded data of the intermediate levelled total field using a 2-D fast Fourier transform (FFT) operator.
5. An altitude correction derived by multiplying the calculated vertical gradient by the aircraft's deviation from the planned surface height is then applied to the original unlevelled magnetic data.
6. Steps 1 to 3 are then repeated using the altitude-corrected magnetic data.
7. Manual inspection of the remaining intersection mismatches and reducing it to zero (where appropriate) by applying the necessary corrections to either the survey or tie lines. Special attention is paid to ensuring that the overall correction profiles are as smooth as possible and that there is no line-to-line correlation in the correction profiles, which implies a misapplied correction.
8. The second vertical derivative of the total field grid is analyzed to ensure that the corrections are sufficient and appropriate. Features that appear along the survey lines in the second vertical derivative may be the result of over-correction or under-correction. In either case, the solution is to revise the correction profile at those intersections.

6.2.3 Calculation and Removal of the International Geomagnetic Reference Field

The International Geomagnetic Reference Field (IGRF) was calculated using the 2015 model year with a constant date, roughly the mid-point for each individual block, as the reference date (see table below). The corrected GPS altitude at each given survey point was specified as the elevation. This value was subtracted from the tie-line or microleveleld levelled data to obtain the residual magnetic field data.

Survey Block	Reference Date for IGRF Calculation
Area 123	2017/09/21
Area 4	2017/09/16
Area 5	2017/10/09

6.2.4 Microlevelling of the Magnetic Data

After control line levelling, any residual flight line noise or "corrugation" in the magnetic field data was further reduced using Paterson, Grant & Watson's microlevelling technique. This technique first involves the generation of line-to-line noise profiles by applying frequency domain sixth-order, high-pass

Butterworth filter and a directional cosine filter perpendicular to the flight-line direction to the gridded data. This "decorrugation" grid is then sampled back into the database. The initial noise profile data is then limited to a user-defined maximum amplitude and then filtered using a Naudy–Dreyer non-linear filter to obtain the microlevelling correction. Finally, the correction and gridded microlevelled data are inspected to ensure no geological signal was removed and an overall improvement in the gridded data was achieved.

The following parameters in Paterson, Grant & Watson's "Miclev" routine were used for Area 123:

- Decorrugation wavelength cutoff: 1 600 m
- Decorrugation grid cell size: 100 m
- Naudy filter length: 1 000 m
- Naudy filter tolerance: 0.0001
- Amplitude limit: 2.0 nT

The following parameters in Paterson, Grant & Watson's "Miclev" routine were used for Area 5:

- Decorrugation wavelength cutoff: 3 200 m
- Decorrugation grid cell size: 200 m
- Naudy filter length: 1 000 m
- Naudy filter tolerance: 0.0001
- Amplitude limit: 1.0 nT

No microlevelling was applied to the Area 4 data.

7 QUALITY CONTROL

7.1 Tests and Calibrations

The full results of the tests and calibrations described below can be found in Appendix A.

a) Compensation Figure of Merit

Aircraft movements induce spurious magnetic fields, which are removed from the magnetic data by the compensator. The efficiency of this removal can be evaluated by conducting a test called a Figure of Merit (FOM). The aircraft flies a series of 3 manoeuvres of ±10° rolls, ±5° pitches and ±5° yaws in each of the traverse- and control-line directions in a magnetically quiet zone (low magnetic gradient). The peak-to-peak amplitudes of the responses obtained on the magnetometer compensated channel are determined for each of the 3 manoeuvre types and for each of the 4 directions. The 12 values are then summed giving the Figure of Merit.

Compensation figure of merit tests were performed by both aircraft after their initial arrival on site and before survey operations commenced. In addition, the calibration and tests were repeated after any significant change to the aircraft or its systems which may have altered its magnetic properties.

In all calibration and subsequent tests performed by the aircraft, the resultant figures of merit for the tail and wing-tip sensors were below the specified threshold of 1.5 nT.

7.2 Daily Field Quality Control

a) Positioning Data

In a Geosoft® Oasis montaj™ database, the corrected GPS data are inspected for gaps and positioning error as indicated by anomalous velocity changes or vertical offsets. The real-time positions are compared to the post-corrected positions for integrity check.

Flight path is examined to detect horizontal deviations that exceed tolerances. Computed velocity is inspected and confirmed to be within tolerances.

The radar altimeter and barometric altimeter data are inspected for anomalous conditions. The computed digital elevation model is compared against known topographical data. Vertical navigation is checked for deviations from the pre-determined flight surface that exceed tolerances.

b) Magnetic Data

Goldak Airborne Surveys' data acquisition system is designed to allow the second pilot to monitor data quality at all times. Both pilots have been trained to operate the equipment and recognize data problems. Automated systems are also in place to draw their attention to anomalous conditions. In addition, the field processor is continually monitoring the magnetic base station via radio link to be on the alert for poor diurnal conditions. The field processor maintains scheduled communication with the aircraft for flight-following purposes and to update the flight crew on weather and diurnal conditions.

After a survey flight, the magnetic and measured gradient data are inspected on a line-by-line basis for gaps, spikes and other anomalous conditions. Magnetic noise levels are monitored using the fourth digital difference and visually. The magnetic base station data are examined for deviations that exceed the contract stated peak-to-peak magnitude and chord lengths. Reflights are assigned where necessary.

A frequency domain plot of the uncompensated and compensated magnetic data is generated through fast Fourier transform on a line-by-line basis and inspected. Through this, the general ongoing performance of the magnetic compensation can be evaluated and any aircraft system-induced magnetic noise can be easily discerned.

Grids of the total field and horizontal gradient data, along with flight path plots, are examined daily to visually compare the correlation of data between lines and across flights.

7.3 Quality Control in the Home Office

a) Review of field processed data

At the home office, the results of the field processing are reviewed at regular intervals throughout the survey and following completion.

b) Review of the final processed data

The results of the levelling of the magnetic data are reviewed on a line-by-line basis through inspection of the total correction profile and intersection mismatch values. Final grid products are visually and statistically inspected for overall quality and validity.

8 FINAL PRODUCTS

8.1 Digital Profile Data

Databases containing the magnetic and radiometric profile data were delivered in Geosoft® .GDB format. The fields included in each respective database are as follows:

Channel	Description	Units
BaseMag_1	Base Station Magnetic Reading	nT
Date	Date	YY-JulianDAY
DEM	Digital Terrain (GPS_Z_Corr-Radar_Alt)	m
direction	Nominal Line Direction	Degrees cw from N
Fiducial	Fiducial Number	-
Flight	Flight Number	-
GPS_Lat_Corr	WGS84 Longitude	Degrees
GPS_Lon_Corr	WGS84 Latitude	Degrees
GPS_Z_Corr	Orthometric Height	m
igrf	IGRF Value	nT
Line	Line Number	-
Mag_anom	Residual Magnetic Field	nT
Mag_B_Lag	Lagged, Compensated Tail Mag	nT
Mag_DiurCorr1	Base Station Corrected Tail Mag	nT
Mag_level	Levellled Tail Mag (Derived from Mag_B_Lag)	nT
Mag_miclev	Microlevelled Mag*	nT
Radar_Alt	Radar Altimeter	m
X	WGS84 Zone 14N Easting	m
Y	WGS84 Zone 14N Northing	m

Table 5 - Final Database Channels

8.2 Grids

Grids of the residual total magnetic field in UTM Zone 14N WGS84 datum coordinates we delivered in Geosoft .GRD format

File	Cell Size
Area_123_Mag_Anom.grd	100
Area_4_Mag_Anom.grd	250
Area_5_Mag_Anom.grd	200

Table 6 - Final Grids

APPENDIX A – SURVEY BLOCK COORDINATES

The WGS84 UTM Zone 14 North coordinates for the survey blocks appear below:

Area 123

Vertex	Easting	Northing	Vertex	Easting	Northing
1	496689	3883145	20	570856	3851833
2	496689	3893227	21	568115	3844273
3	405275	3913026	22	570679	3843389
4	387137	3863345	23	565728	3829773
5	387329	3853049	24	556090	3829419
6	481256	3832751	25	552046	3818314
7	499693	3809175	26	510296	3818448
8	620476	3809981	27	514785	3831980
9	622890	3816979	28	510263	3841894
10	609699	3821759	29	503126	3844510
11	589826	3841688	30	502803	3842896
12	557387	3874977	31	491016	3846997
13	551900	3859786	32	492146	3850872
14	551250	3860040	33	489465	3851841
15	548179	3851836	34	492437	3859980
16	550495	3850977	35	497891	3859526
17	552102	3854713	36	497762	3870276
18	554963	3853659	37	492309	3870917
19	556267	3857182	38	496689	3883145

Table 7 – Area 123 400 m spaced Coordinates

Area 123 200 metre Infill

Vertex	Easting	Northing
1	491039	3846992
2	492214	3850808
3	489642	3851830
4	492640	3859991
5	507292	3859633
6	519234	3857844
7	516713	3850314
8	516560	3850433
9	513306	3841540
10	503544	3844470
11	502947	3842954
12	491056	3847009
13	491039	3846992

Table 8 – Area 123 200 m spaced Coordinates

Area 123 4 00m Infill Lines

Vertex	Easting	Northing
1	498356	3861260
2	498356	3870119
3	493722	3871346
4	501218	3891108
5	555326	3871754
6	551237	3860033
7	550965	3860579
8	548239	3851856
9	545104	3853082
10	543741	3848449
11	535973	3851311
12	533928	3847903
13	524524	3851720
14	523298	3847767
15	517710	3849948
16	523843	3866439
17	521662	3866439
18	518936	3858807
19	498765	3860987

Table 9 – Area 123 4000 m spaced Coordinates

Area 4

Vertex	Easting	Northing
1	506300	4000631
2	560065	4037464
3	530608	4079229
4	477440	4042797

Table 10 – Area 4 Coordinates

Area 5

Vertex	Easting	Northing
1	651416	4029641
2	693668	4058271
3	714427	4027756
4	715645	3926779
5	693527	3912269
6	679559	3932600
7	657305	3917524
8	624935	3965380
9	672476	3998635
10	651416	4029641
11	651416	4029641
12	693668	4058271
13	714427	4027756

Table 11 – Area 5 Coordinates

APPENDIX B – TEST AND CALIBRATION RESULTS

B.1 Compensation Figure of Merits

Compensation / Figure of Merit Test Analysis

Project	Central Oklahoma
Flight	2
Aircraft	C-GJBB
Date	2017-08-13
Julian Day	225

Pilot	Mathieson
Copilot	Biesenthal
Processor	Heath

Test Summary

MB FOM	0.79

Test Location	Altus
Reason for Comp / FOM	Start of Project

Air Time	0.9
Test Time	0.5
Ferry Time	0.4

RMS AADCII Compensator Statistics

	Uncomp Std Dev	Comp Std Dev	IR	Solution Norm
Left Wing M1	1.90E+00	3.65E-02	51.9	53.9
Right Wing M2	2.21E+00	4.98E-02	42.7	58.3
Tail Top M3				
Tail Lower M4	3.03E-01	2.11E-02	14.3	16.5
Lateral Grad G1	5.73E+00	1.03E-01	55.8	42.6
Long Grad G2	1.72E+00	1.54E-01	111.5	65.3
Vert Grad G3				
Memory Slot	4			

FOM Analysis

Bottom Tail Magnetometer (MBc)					
	North	East	South	West	Sum
Pitch	0.09	0.09	0.09	0.09	0.36
Roll	0.04	0.04	0.04	0.05	0.17
Yaw	0.04	0.09	0.04	0.09	0.26
Sum	0.17	0.22	0.17	0.23	0.79

Table 12 - C-GJBB Compensation Figure of Merit, August 13

Compensation / Figure of Merit Test Analysis

Project	Central Oklahoma
Flight	26
Aircraft	C-GJBB
Date	2017-09-11
Julian Day	254

Pilot	Mathieson
Copilot	Biesenthal
Processor	Heath

Test Summary

MB FOM	0.87

Test Location	Altus
Reason for Comp / FOM	for orientation of Northern Block Lines

Air Time	0.6
Test Time	0.6
Ferry Time	

RMS AADCII Compensator Statistics

	Uncomp Std Dev	Comp Std Dev	IR	Solution Norm
Left Wing M1	1.78E+00	3.67E-02	54	53.7
Right Wing M2	2.28E+00	5.27E-02	43.2	58.4
Tail Top M3				
Tail Lower M4	2.84E-01	2.44E-02	11.6	17.1
Lateral Grad G1	5.59E+00	1.07E-01	52.1	43.2
Long Grad G2	1.80E+00	1.61E-01	112.1	63.6
Vert Grad G3				
Memory Slot	5			

FOM Analysis

Bottom Tail Magnetometer (MBc)					
	North	East	South	West	Sum
Pitch	0.11	0.08	0.07	0.11	0.37
Roll	0.03	0.04	0.02	0.04	0.13
Yaw	0.11	0.1	0.08	0.08	0.37
Sum	0.25	0.22	0.17	0.23	0.87

Table 13 - C-GJBB Compensation Figure of Merit, September 11

APPENDIX C – OPERATIONS REPORTS

Goldak Airborne Surveys Operations Report

Central Oklahoma

August 07 to August 13

2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Altus, OK
Contact:	306-290-3881

Summary	
Project Total	29075
Remaining	0
Flown this week	
Flown to date	0

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon August 07		C-GJBB												
Tues August 08		C-GJBB												
Wed August 09		C-GJBB												Aircraft and crew leave Saskatoon. Clear customs and overnight in Williston, ND
Thurs August 10		C-GJBB												Arrive in Altus Base GPS set up
Fri August 11	1	C-GJBB	1.3			1.3				60				Cloud, T-Storms most of the day. Basemags set up Comp Flight attempted
Sat August 12		C-GJBB								100				Cloud T-Storms
Sun August 13	2	C-GJBB	0.9			0.9				80				Overcast for most of the day, clearing around 5 pm local compensation flight performed => OK FOM of 0.78
Weekly Total			2.2	0	0	2.2	0	0	0					
Total to Date			0	0	0	0	0	0	0					

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

August 14 to August 20
2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Altus, OK
Contact:	306-290-3881

Summary	
Project Total	29075
Remaining	22608
Flown this week	6467
Flown to date	6467

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon August 14	3	C-GJBB	0.2		4.5	4.7	1140	1140						Flight abbreviated for media event
Tues August 15	4	C-GJBB	0.2		6.2	6.4	1521	1521		50				Rain in the morning, clearing around noon.
Wed August 16	5	C-GJBB	0.2			0.2						100		Gear door problem, returned to base.
														Red River A/C looking at the issue
Thurs August 17		C-GJBB										100		gear door bring fixed
Fri August 18	6	C-GJBB	0.4		5.2	5.6	1162	1162						
Sat August 19	7	C-GJBB	0.1		5.8	5.9	1250	1250						
Sun August 20	8	C-GJBB	0.2		5.9	6.1	1394	1394						

Weekly Total	1.3	0	27.6	28.9	6467	6467	0
Total to Date	3.5	0	27.6	31.1	6467	6467	0

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

August 21 to August 27
2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Altus, OK
Contact:	306-290-3881

Summary	
Project Total	29075
Remaining	15487
Flown this week	7121
Flown to date	13588

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon August 21	9	C-GJBB	0.3		5.8	6.1	1394	1394						
Tues August 22	10	C-GJBB	0.4		5.7	6.1	1394	1394						
Wed August 23	11	C-GJBG	1.3		0.5	1.8	118	103	15	90				low overcast
Thurs August 24	12	C-GJBB	0.5		5.7	6.2	1394	1394						
Fri August 25		C-GJBB								100				heavy rain, low overcast
Sat August 26	13	C-GJBB	0.2		6.1	6.3	1493	1482	11					
Sun August 27	14	C-GJBB	0.3		5.8	6.1	1354	1354						

Weekly Total	3	0	29.6	32.6	7147	7121	26
Total to Date	6.5	0	57.2	63.7	13614	13588	26

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

August 28 to September 3
2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Altus, OK
Contact:	306-290-3881

Summary	
Project Total	29075
Remaining	8205
Flown this week	7282
Flown to date	20870

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon August 28	15	C-GJBB	0.7		5.2	5.9	1268	1268						
Tues August 29	16	C-GJBB	0.6		5.4	6.0	1324	1324						
Wed August 30	17	C-GJBB	0.1		6.1	6.2	1346	1346						
Thurs August 31	18	C-GJBB	0.3		5.5	5.8	1193	1066	127					
Fri September 01		C-GJBB										100		Aircraft maintenance
Sat September 02	19	C-GJBB	0.3		5.7	6.0	1126	1126						
Sun September 03	20	C-GJBB	0.3		5.7	6.0	1152	1152						

Weekly Total	2.3	0	33.6	35.9	7409	7282	127
Total to Date	8.8	0	90.8	99.6	21023	20870	153

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

September 04 to September 10
2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Altus, OK
Contact:	306-290-3881

Summary	
Project Total	44671
Remaining	20431
Flown this week	3370
Flown to date	24240

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon September 04	21	C-GJBB	0.5		5.4	5.9	1221	1221						
Tues September 05		C-GJBB								100				High winds and turbulence
Wed September 06	22	C-GJBB	0.4		5.1	5.5	848	848						
Thurs September 07	23	C-GJBB	0.5		3.8	4.3	546	527	19					
Fri September 08		C-GJBB									100			Active Diurnal
Sat September 09	24	C-GJBB	0.6		4.5	5.1	774	774						
Sun September 10		C-GJBB											100	Pilot is ill

Weekly Total	2	0	18.8	20.8	3389	3370	19
Total to Date	10.8	0	109.6	120.4	24412	24240	172

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

September 18 to September 24
2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Bisenthal
Processor:	Heath
Base:	Altus, OK
Contact:	309-290-3881

Summary	
Project Total	44671
Remaining	14878
Flown this week	2232
Flown to date	29793

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon		C-GJBB								100				High wind, turbulence, T-Storm activity
September 18														
Tues		C-GJBB								100				Low level wind shear, turbulence
September 19														
Wed		C-GJBB								100				Low level wind shear, turbulence
September 20														
Thurs		C-GJBB								100				High wind and turbulence
September 21														
Fri	30	C-GJBB	1.4		3.5	4.9	771	771						Area4
September 22														Turbulent throughout
Sat	31	C-GJBB	2.1		3.1	5.2	646	646						Area 4: 377 km...completes Area 4
September 23														Area 5: 269 km
														Turbulent throughout
Sun	32	C-GJBB	1.7		3.6	5.3	815	815						Area 5
September 24														Turbulent

Weekly Total	5.2	0	10.2	15.4	2232	2232	0
Total to Date	21.2	0.6	135.3	157.1	30214	29793	421

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

October 02 to October 08

2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Chickasha, OK
Contact:	306-290-3881

Summary	
Project Total	44671
Remaining	9148
Flown this week	3212
Flown to date	35523

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon October 02		C-GJBB								100				Rain
Tues October 03	36	C-GJBB	0.9			0.9				100				Flight aborted. Low ceilings
Wed October 04		C-GJBB								100				Rain, Thunderstorms
Thurs October 05		C-GJBB												Relocated to Chickasha
Fri October 06	37	C-GJBB	1.1		5.0	6.1	1203	1203						
Sat October 07	38	C-GJBB	1.0		4.7	5.7	1001	1001						
Sun October 08	39	C-GJBB	0.9		4.8	5.7	1008	1008						

Weekly Total	3.9	0	14.5	18.4	3212	3212	0
Total to Date	30.7	0.6	160.6	191.9	35944	35523	421

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

September 25 to October 01
2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Altus, OK
Contact:	306-290-3881

Summary	
Project Total	44671
Remaining	12360
Flown this week	2518
Flown to date	32311

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon September 25		C-GJBB								100				Rain, Lightning, Low overscast
Tues September 26		C-GJBB								100				Rain, Low overcast
Wed September 27		C-GJBB								100				Rain, Low overcast
Thurs September 28		C-GJBB								100				Low overcast
Fri September 29	33	C-GJBB	1.9		2.7	4.6	668	668		25				Weather cleared by mid-day
Sat September 30	34	C-GJBB	1.9		4.1	6.0	1003	1003						
Sun October 01	35	C-GJBB	1.8		4.0	5.8	847	847						

Weekly Total	5.6	0	10.8	16.4	2518	2518	0
Total to Date	26.8	0.6	146.1	173.5	32732	32311	421

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

October 09 to October 15

2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Chickasha, OK
Contact:	306-290-3881

Summary	
Project Total	44671
Remaining	7672
Flown this week	1476
Flown to date	36999

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon October 09		C-GJBB										100		Aircraft maintenance
Tues October 10		C-GJBB										100		Aircraft maintenance
Wed October 11		C-GJBB										100		Aircraft maintenance
Thurs October 12		C-GJBB								50		50		Aircraft maintenance complete by midday.
														High winds and turbulence.
Fri October 13	40	C-GJBB	1.0		5.1	6.1	1201	952	249		20			Some diurnal activity during flight
Sat October 14	41	C-GJBB	1.3		2.7	4.0	595	524	71	40	20			Flight shortened, heavy winds
Sun October 15		C-GJBB								100				High winds and turbulence

Weekly Total	2.3	0	7.8	10.1	1796	1476	320
Total to Date	33	0.6	168.4	202	37740	36999	741

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

October 16 to October 22

2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Chickasha, OK
Contact:	306-290-3881

Summary	
Project Total	44671
Remaining	3395
Flown this week	4277
Flown to date	41276

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon October 16	42	C-GJBB	1.2		3.9	5.1	928	928						
Tues October 17	43	C-GJBB	1.1		4.1	5.2	1033	1033						
Wed October 18	44	C-GJBA	0.9		2.9	3.8	664	597	67	30				High wind and turbulence shortened flight
Thurs October 19	45	C-GJBB	1.4		2.7	4.1	604	604						
Fri October 20		C-GJBB								50				High winds. Unable to get into military areas; alternate flight plans not yet determined
Sat October 21		C-GJBB								100				High winds and turbulence
Sun October 22	46	C-GJBB	0.4		5.9	6.3	1148	1115	33					

Weekly Total	5	0	19.5	24.5	4377	4277	100
Total to Date	38	0.6	187.9	226.5	42117	41276	841

Goldak Airborne Surveys Operations Report

USGS - Central Oklahoma

October 23 to October 29

2017

Aircraft and Crew	
Aircraft:	C-GJBB
Pilot:	Mathieson
Copilot:	Biesenthal
Processor:	Heath
Base:	Chickasha, OK
Contact:	309-290-3881

Summary	
Project Total	44671
Remaining	-1031
Flown this week	4426
Flown to date	45702

			Flight Times (h)				Production (km)			Unservicability (%)				
	Flight	Aircraft	Ferry	Test	Survey	Total	Flown	Accepted	Rejected	Weather	Diurnal	Equipent	Crew	Notes
Mon October 23	47	C-GJBB	0.4		5.6	6.0	1019	1019						
Tues October 24	48	C-GJBB	0.6		5.6	6.2	921	848	73					
Wed October 25	49	C-GJBB	0.3		4.7	5.0	808	794	14					
Thurs October 26	50	C-GJBB	0.3		5.3	5.6	905	905						
Fri October 27		C-GJBB												
Sat October 28	51	C-GJBB	0.8		4.2	5.0	860	860						Completes Project
Sun October 29		C-GJBB												

Weekly Total	2.4	0	25.4	27.8	4513	4426	87
Total to Date	40.4	0.6	213.3	254.3	46630	45702	928