How airborne gravity surveys can make sense for cost effective exploration

Consensus amongst geophysical professionals is that the overall number of airborne gravity surveys will increase in the coming years. In this article Luis Sander, co-president, Sander Geophysics (SGL), based in Canada, explains with some case histories how the company is deploying its Airborne Inertially Referenced Gravimeter (AIRGrav) system targeted at producing better results than traditional airborne gravity systems.

In 1992 SGL, which owns and operates nine aircraft for exploration and environmental mapping surveys worldwide, undertook a project to design an airborne gravimeter. The five year research and development project resulted in the AIRGrav system, which has been used for airborne surveying since 1997. The majority of these surveys have been conducted for the petroleum industry, as well as some applications to mining exploration.

The AIRGrav system consists of a three-axis gyro stabilized inertial platform with three orthogonal accelerometers. Unlike gravimeters used in traditional airborne surveys, SGL's AIRGrav system does not use any spring-type apparatus. The accelerometer is held within 10 arc seconds (0.0028 degrees) of level, by a Shuler tuned inertial platform, monitored through the complex interaction of gyroscopes and accelerometers. The inertial platform ensures that the gravimeter remains oriented vertically, independent of the manoeuvres of the aircraft. The entire AIRGrav system uses weapons / space quality hardware and was specifically designed for the airborne environment.

An important component of the airborne gravity system is the on-board laser altimeter, enabling the calculation of a very accurate digital terrain model in the survey area. Poorly modelled terrain data could cause a significant error in the processed gravity data. SGL's airborne gravimeter is tolerant of turbulent flying conditions. It delivers good results when flown under normal weather and turbulence conditions, similar to the conditions required to fly a magnetometer survey.

The AIRGrav system itself is lightweight, with an installed weight of less than 100 kg. This allows it to be installed in survey aircraft in conjunction with other geophysical equipment, including that necessary for magnetic surveys (Figure 1).

Data Processing

On a typical survey flight the accelerations in an aircraft due to turbulence reach 0.1 G or 100,000 mGal, while the AIRGrav system is designed to measure gravity to better than 1 mGal. To obtain an accurate value of gravity in this noisy environment, the vertical accelerations of the aircraft movement must be separated from the gravity signal. A system of high resolution GPS receivers are used to measure the aircraft accelerations, and proprietary processing software has been designed to extract the high frequency vertical accelerations of the aircraft. SGL has also developed software to correct the recorded gravity data to derive Bouguer anomaly line data and grids.

Tests have shown that anomalies of less than one mGal can be accurately resolved. Generally, a geological anomaly will resemble half a sine wave, thus using standard filters, the AIRGrav system will resolve anomalies recorded for approximately 1800 m at survey flying speed. When the used in a helicopter, the ground speed is significantly lower and a one mGal anomaly can be detected over one km.

Recent survey results

The company has conducted numerous airborne gravity surveys since 1997 using the new system. Results indicate extremely good correlation between AIRGrav and ground gravity surveys, as well as between AIRGrav surveys and known oil and gas fields. The following examples briefly outline the findings from three of these surveys, two over oil and gas fields, and one over a mining district.

Figure 1 *Cessna Grand Caravan fitted with an AIRGrav and magnetometer surveying system*

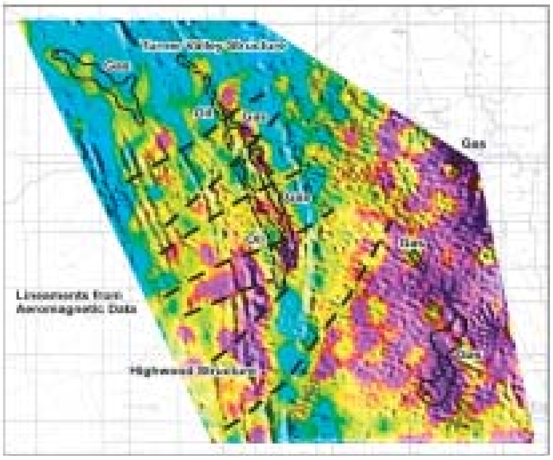

Figure 2 *First vertical derivative of AIRGrav data with a shadow of the first vertical derivative of the magnetic data. The known oil fields are shown.*

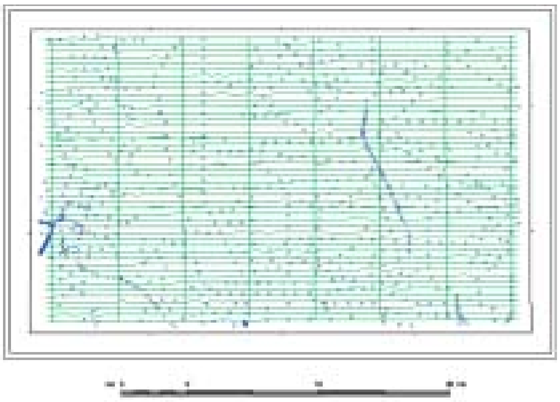

Figure 3 *Gravity Data Coverage. AIRGrav flight lines are green, ground data points are blue crosses.*

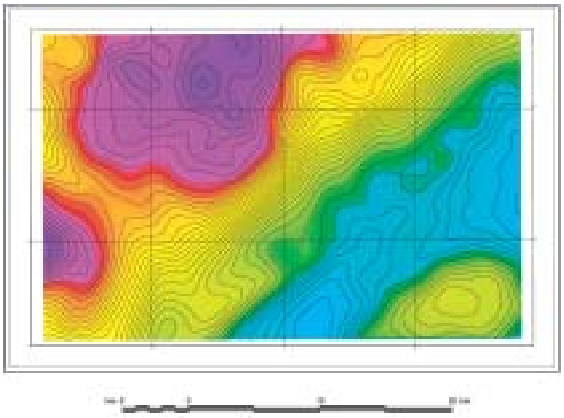

Figure 4 *AIRGrav bouguer data grid with 1 mGal contour levels.*

Turner Valley

In 2001, SGL flew a large AIRGrav survey in Western Canada over the Turner Valley area, a well known oil and gas producing region south of Calgary, Alberta. The survey area covered the foothills of the Rocky Mountains. The general trend of the geology in the area is north-northwest/south-south-east. A total of 12 500 line km were flown using a fixed-wing aircraft to simultaneously collect AIRGrav and magnetometer data. The survey was completed in less than five weeks, over very mountainous terrain, ranging from approximately 1000 m ASL to approximately 2000 m ASL. East-west traverse lines were spaced at 250m and north-south control lines at 1000m.

Figure 2 shows a representation of the AIRGrav data and the aeromagnetic data acquired during the Turner Valley survey. The colour image displays the first vertical derivative of the Bouguer gravity, with the warm colours representing gravity highs. The grey shades are the shadow of the first vertical derivative of the aeromagnetic data. The western side of the data set is dominated by north-south trending faults associated with the foothills region. The eastern side of the area consists of flat lying sediments. Gas and oil producing areas are outlined by solid and dotted lines respectively. The long north south trending field in the centre of the area is the Turner Valley field, first discovered in 1914. The Turner Valley field, and the Quirk Creek Field, in the northwest of the area are generally associated with gravity highs. East-west trending lineaments, marked with dashed lines, were determined by joining terminations on the aeromagnetic data. The same lineaments also mark changes in the gravity signal, and offset the Turner Valley field.

Timmins Survey

SGL conducted an AIRGrav survey immediately north of Timmins, Ontario, during the spring of 2003. The survey flight lines were spaced at 500 m by 5000 m, flown at a constant altitude of 1500 ft above sea level, which corresponds to about 300 m above the ground level. The altitude was chosen to comply with Canadian air regulations for flying over built-up areas. Four production flights were performed totalling 1836 line km. The airborne data were compared with ground Bouguer gravity data acquired in previous years. The ground data consists of 573 stations acquired in 2001 and 213 stations acquired between 1949 and 1970. A map showing the relative location of the airborne survey flight lines and all ground data points is given in Figure 3.

The ground gravity stations have a nominal spacing of 1 km but, as with most ground surveys, the station spacing was not regular or complete. Airborne surveys are able to record data over a more uniform area, producing a more complete and regularly spaced data set over a given area.

A grid was created from the ground gravity data points using a minimum curvature gridding algorithm and 250 m

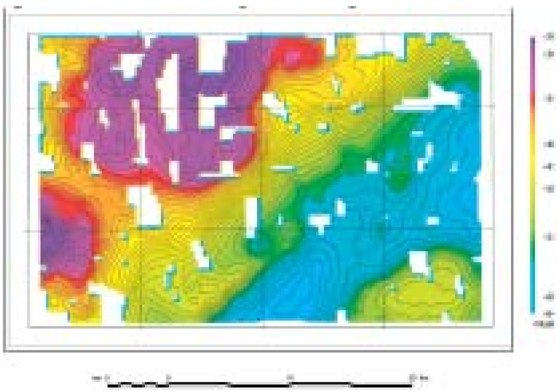

Figure 5 *Ground Bouguer data grid with 1 mGal contour levels*

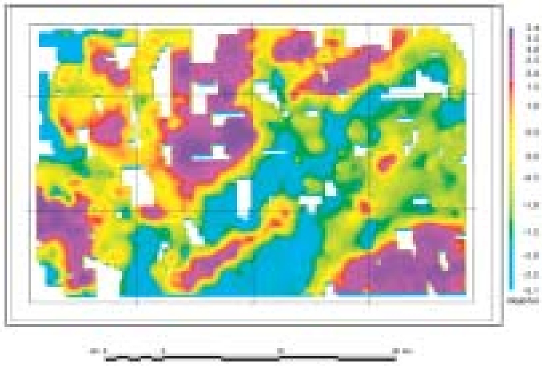

Figure 7 *First vertical derivative of the ground grid after a 200 m upward continuation.*

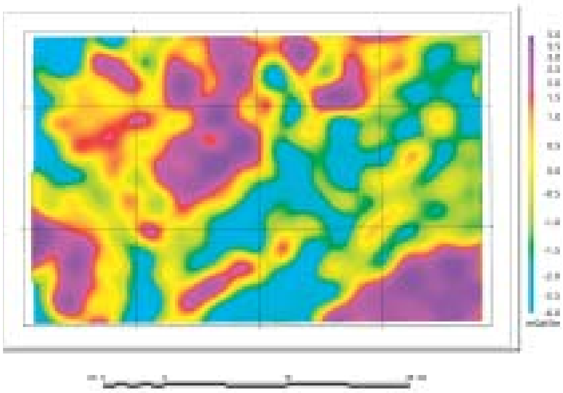

Figure 6 *First vertical derivative of the AIRGrav data grid*

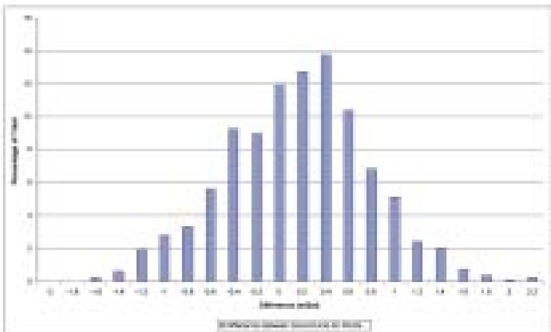

Figure 8 *Absolute Value of difference between the ground and air gravity data points in the Timmins area*

grid cell size. In order to match the AIRGrav data, the ground data was upward continued by 200 m, the average aircraft height above the ground. Areas that were more than three grid cells away (750 m) from a ground data point were left as nulls in the grid, to indicate where ground coverage is incomplete. Since the AIRGrav data was gathered at 500 m line spacing, the AIRGrav grid is complete and regular, with no nulls (white spaces). The AIRGrav grid and the ground data grid are given as Figures 4 and 5, respectively.

As these figures show, the AIRGrav and ground data match very well. They are displayed with identical contours, colour levels, and grid cell sizes.

Details in the data grids can be enhanced by calculating the first vertical derivative (FVD). The following figures illustrate the excellent correlation of the FVD grids of the AIRGrav data (Figure 6) and the ground data (Figure 7).

Simple grid comparisons are not entirely valid due to the uneven spacing of the ground data. A more comprehensive way of comparing the two data sets is to compare the upward continued values of the 780 ground data points with data interpolated from the AIRGrav grid at corresponding locations. The standard deviation of the differences between the air and ground readings of the 780 points was 0.62 mGal. A plot of this comparison is seen in Figure 8.

Oil field test survey

As a test survey, SGL recently flew an airborne gravity survey over a major oil field. Data from this survey is currently confidential, but will be released for publication in the near future. The survey area has been extensively covered by a dense evenly spaced ground gravity survey. After the processing of SGL's airborne survey was complete, the ground data were provided for verification of the AIRGrav results.

The gravity grids from both surveys were in excellent agreement. The ground data was acquired in conjunction with a 3D seismic survey. The standard deviation of the differences between the airborne data and the approximately 4000 ground data points was 0.27 mGal. This indicates a better agreement than that calculated for the Timmins survey. Several factors combine to contribute to this improvement. Probably the most significant is the quality of the ground data points. As well, the geological signal from the deep basin of the test survey is very accurately represented by the AIRGrav data, while the Timmins survey area contains a near surface high frequency geological signal, which is attenuated to greater extent with flying height.

A close examination of the survey area covered by dense ground readings with approximately 300 m station spacing reveals a very good agreement with the AIRGrav data. Co-located gravity anomalies of less than 0.5 mGal were found in both the ground data and the AIRGrav data.

Conclusions

The SGL AIRGrav system can be used to supplement or replace ground gravity surveys. An AIRGrav survey can be completed in a fraction of the time needed to complete a ground survey and can be flown with no environmental impact on the survey area. Traditional aeromagnetic surveys can also be flown simultaneously providing additional geophysical data for very little extra cost.