Coordinated by Dale Bird

AIRGrav results: a comparison of airborne gravity data with GSC test site data

Malcolm Argyle, Stephen Ferguson, Luise Sander, and Stephan Sander, Sander Geophysics, Ottawa, Canada

Sander Geophysics (SGL) has developed an airborne gravimeter system that uses three orthogonal accelerometers mounted on a three-axis, gyroscopically stabilized platform. The system, called AIRGrav (Airborne Inertially Referenced Gravimeter), was designed specifically for airborne use. This has resulted in an instrument with significant advantages over the modified sea gravimeters commonly used for airborne surveying; the main benefit of the new instrument is that it is more stable in attitude and less subject to noise from horizontal accelerations.

As a result, surveys can be flown under much less favorable flight conditions than needed by other systems, making its operations more economical. Test results show no appreciable degradation of signal quality due to moderate turbulence. Good gravimeter data have been obtained under aircraft accelerations up to 4 m/s^2 (peak to peak) for turbulence with a frequency of 2 Hz.

Method. It is almost impossible, when performing airborne surveys, to avoid some degree of air turbulence. The resulting horizontal and vertical accelerations of the aircraft can be on the order of hundreds of thousands of mGal. Even a very slight deviation of the gravity sensor from the vertical will influence the gravity measurements. Vertical accelerations of the aircraft combine directly with the measurement of gravity. Our gravimeter system addresses these issues in a way that produces reliable results when flying in less than ideal conditions.

The system allows simple, regular calibration of its sensors. Good temperature control and modeling ensure that the gravity sensor is stable to 1 mGal or better over the longest flight period expected.

An airborne gravimeter determines gravity by measuring the vertical acceleration (including gravity) in the aircraft, correcting for the effects of the rotation of the earth and the movement of the platform over the globe, and then subtracting GPS-derived vertical accelerations of the aircraft. Precise phase-processed GPS determines locations and velocities for Eötvös effects and vertical accelerations. The vertical accelerations are the most sensitive to GPS noise.

Two filtering methods were compared—filtering along each individual flight profile and filtering adjacent lines after gridding. A series of filters with midpoint cutoffs ranging from 40 s to 3 minutes was used on the profile data. At 100 knots this corresponds to half sine wave distances of 1.1-4.3 km. The half sine wave resolution gives a rough indication of the smallest anomaly that the system might detect.

Editor's note: Several new systems have been recently developed for acquiring airborne gravity data and airborne gravity gradiometry data. Therefore beginning with this month's Meter Reader column, a special series of columns will spotlight all *commercial systems that are now available to the exploration industry. First in this series is a paper delivered by Sander Geophysics Ltd. at the SEG Annual Meeting and Exposition in Calgary, 2000. Successive* TLE *Meter Reader columns will feature systems developed and/or operated by BHP Minerals, Fugro Airborne Surveys, Carson Services Inc., and Edcon Inc.*

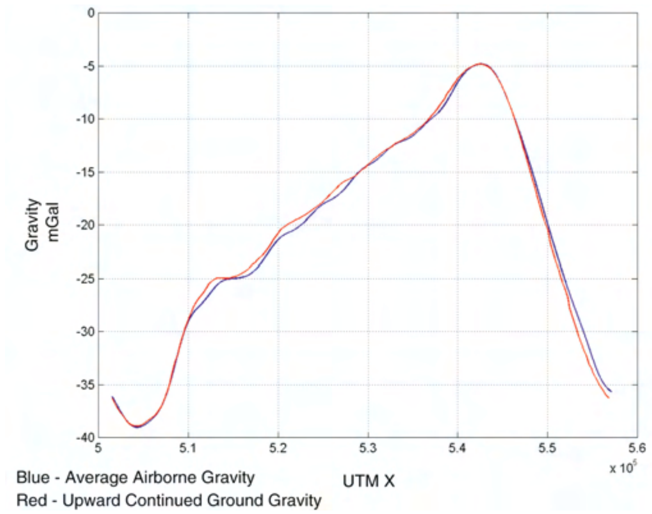

Figure 1. Comparison of airborne and ground gravity data.

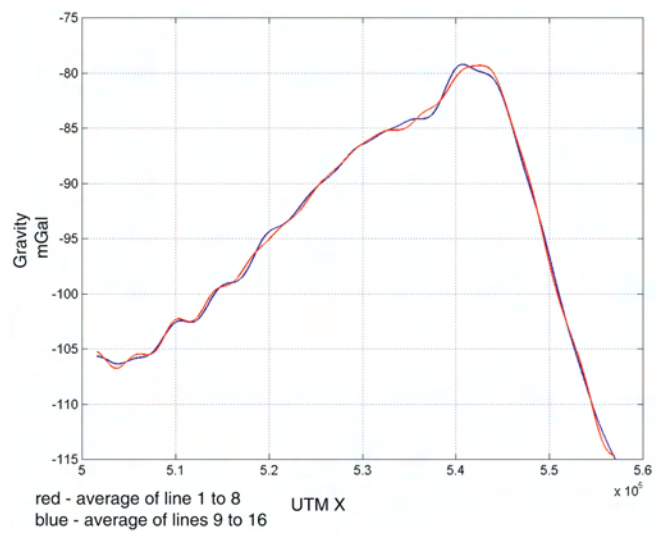

Figure 2. Terrain corrected gravity data.

Close line spacing was approximated by averaging a line 2-17 times. Noise levels were determined by comparing flight data to ground truth, and to an average of the same line flown many times.

Example. SGL tested the system over an area east of Ottawa, and in a mountainous area of western North America; both have dense ground gravity data coverage. Acquired data were compared with the ground data and with numerous reflights of the same line to analyze system performance and determine optimal processing parameters.

Figure 1 compares a test line, which was reflown numerous times under various conditions, to upward continued ground data. The line was flown at a constant altitude above mountainous terrain with vertical differences

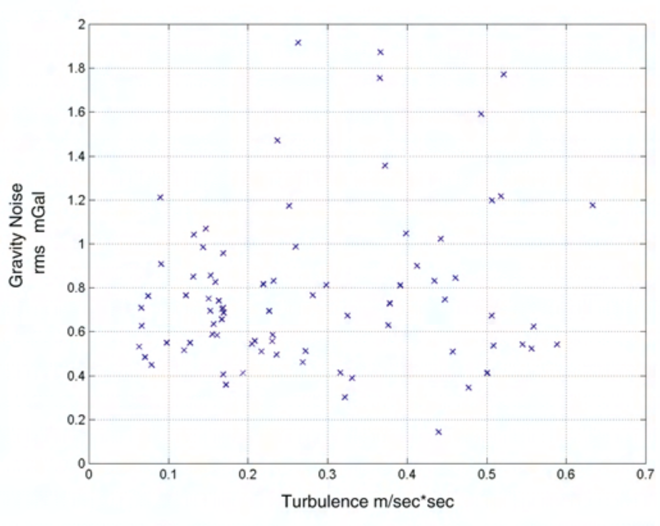

Figure 3. Gravity noise versus turbulence.

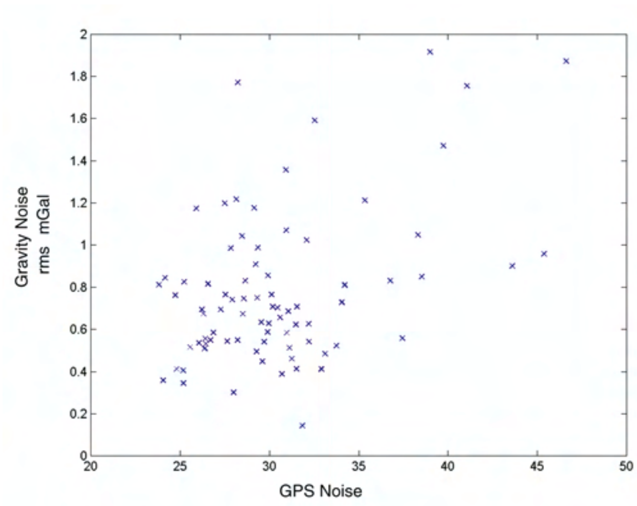

Figure 4. Gravity noise versus GPS noise.

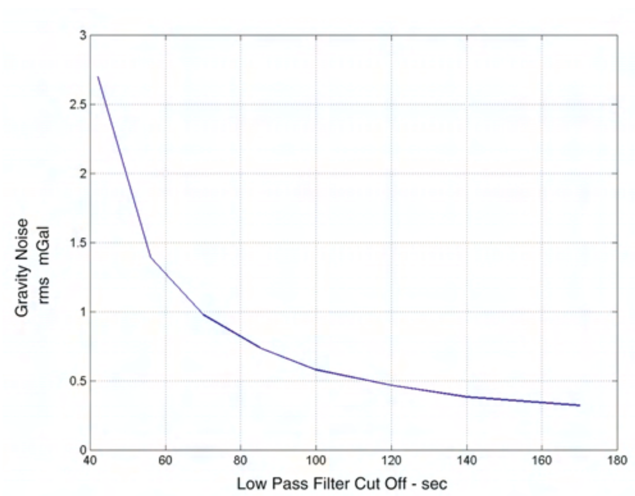

Figure 5. Effect of filter length on noise reduction.

of about 1000 m.

A small shift (less than two mGal) was applied to the data on a flight-by-flight basis, but no sloping corrections or other leveling adjustments have been applied. An 84-s FFT filter (0% pass at 60 s and 100% pass at 144 s) removed high-frequency noise. At the nominal 100-knot survey speed, this results in a half sine wave ground resolution of 2.2 km. The two data sets agree to within a standard deviation of 0.4 mGal.

The ground data have nominal accuracy of 0.1 mGal, and a portion of the remaining error appears to come from the effects of upward continuation of a 2-D profile.

Figure 2 compares two eight-line averages from separate data sets to give an idea of repeatability. The rms difference between the data sets is less than 0.3 mGal.

Turbulence. To evaluate the effect of turbulence on the lines, we have compared the standard deviation of the vertical accelerations on the gravimeter to the gravity noise for five-minute periods on the same test lines (Figure 3). The turbulence levels experienced on this survey had no noticeable effect on the gravity data. The slope of a line fitted to these points is almost zero, and some of the segments flown under the most turbulent conditions have the least gravity noise. These lines were flown under normal daytime conditions over three weeks. The turbulence ranged from calm to moderate.

We also performed the same procedure on a similar data set but included some flights with much more severe turbulence. The most turbulent flights were near the practical limit for survey flying (i.e., conditions where it would be very unpleasant to be a passenger in the aircraft). In this case there was some increase in gravity noise with turbulence, especially for shorter filter lengths. However the increase in gravity noise did not really start until the turbulence reached an rms of 0.6 m/s^2, or 60 000 mGal (the maximum level in the test lines in Figure 3).

GPS accelerations. GPS measurements of the vertical accelerations during the time of each line were also compared with gravity noise. Figure 4 plots GPS noise measured from one ground station to another against the rms gravity noise, for the same test lines as the earlier turbulence graph. To process the GPS data, one of the ground stations was treated as a mobile station while the other was treated as a normal stationary ground station. Accelerations were calculated by double differencing the nominally "mobile" ground station, and were then compared to gravity noise levels for the same time periods. There appears to be some correlation between data sets. This measure of GPS noise captures the effects of satellite geometry, ionospheric noise, and ground station receiver noise and multipath, but not multipath on the aircraft.

Line and grid filtering. Filtering is an important aspect of airborne gravity processing. The effects of averaging and filtering the lines were evaluated, using the test line. An average of 17 lines was used as a standard to compare individual lines. The test lines were filtered with a range of low-pass filters to evaluate the effect of filter length on noise level.

Figure 5 shows rms gravity noise plotted against the filter length. The noise level drops off quickly as the filter length increases, indicating noise is concentrated in higher frequencies. To determine the effect of averaging on the total noise level, two, three, four, five, eight, and 17 lines were averaged. Figure 6 shows the noise reduction effect of averaging lines by plotting noise against the number of lines averaged. Before averaging, lines were filtered with various low-pass filters, and the effect of averaging for each fil-

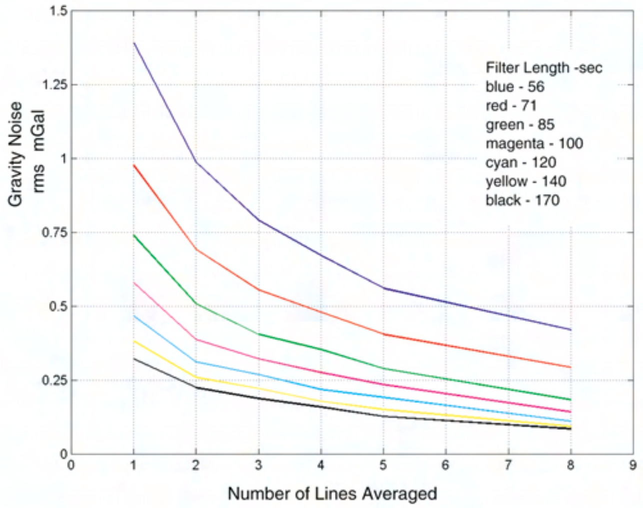

Figure 6. Effect of line averaging on noise reduction.

ter is plotted. The effect of close line spacing was evaluated because of the practical applications for airborne surveys. Flying a survey with line spacing closer than the filter length is similar to repeating lines—the grid data can be filtered to reduce the noise level on the grid to much less than the noise on any individual profile. The reduction will not be quite as much as the values shown on Figure 6, because the lines are not flown exactly on top of each other; but, on the other hand, the grid itself will be more consistent because there would be less interpolation.

Figure 7 is the first vertical derivative of the terrain-corrected gravity data from a survey with line spacing of 3 km. To demonstrate the effectiveness of closer line spacing, SGL flew a few infill lines with line spacing of 1 km. (Figure 8). The detail between the lines is much improved as a result of better sampling especially where the trends are at 45° to the line direction. Some highs and lows along some original lines, which were probably exaggerated by noise, are moderated as a result of the averaging effect of the closer line spacing.

Figure 9 shows the first vertical derivative of more of the survey area. Even in the area with line spacing of 3 km, anomalies with amplitude of less than 1 mGal are continuous from line to line across 30 km.

Conclusions. The three-axis inertially stabilized platform system provides a stable environment for an airborne gravimeter. Precise differential GPS processing techniques are required to remove the dynamic effects of the aircraft.

The system is relatively tolerant of turbulence, with no discernable effect until the turbulence level becomes severe. The system can be used in moderately turbulent conditions in a standard geophysical survey aircraft. This has large economic implications as better tolerance of turbulence means better productivity by crews and faster completion of surveys. Drape flying over terrain is also possible because the system is not affected by the inherent horizontal and vertical accelerations, which are similar to turbulence accelerations. We have tested the system by drape flying in moderate to severe topography, with little or no increase in the gravity noise level. Drape flying makes surveys over rugged terrain much more practical, as the aircraft can maintain a reasonable terrain clearance even if there are large topographic differences.

Averaging adjacent lines on a grid with close line spacing has practical implications for survey flying. Our results show that the time that the aircraft is over the survey area is much more important than the speed of the survey aircraft for all but the highest frequencies. The same noise level and resolution can be achieved by a variety of survey speeds and line spacing. Closer line spacing means surveys can be flown at slightly higher speeds, which are generally safer. Survey grids with close line spacing have a much lower noise level than that of any individual survey profile.

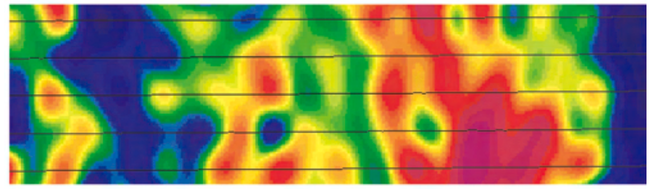

Figure 7. Gravity data with line spacing of 3 km.

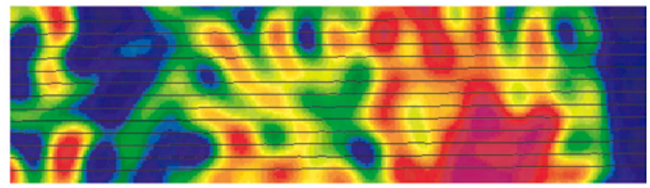

Figure 8. Gravity data with line spacing of 1 km.

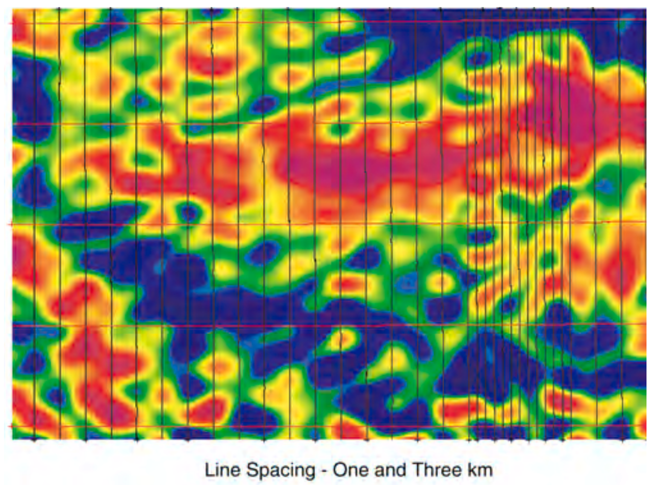

Figure 9. Gravity data with line spacing of 3 km (left) and 1 km (right).

Based on values derived from the test lines, we calculated the expected accuracy for surveys of various resolutions and line spacing. For a fixed-wing system flown at 100 knots, tests indicate data repeatability of better than 0.2 mGal rms with 2.2 km half sine wave resolution for 300-m line spacing, 0.5 mGal with 1.5 km resolution for 200-m line spacing, and 0.5 mGal with 2.2 km resolution for 1-km line spacing. LE

Acknowledgments: The comparison ground gravity data used in this study were provided by the Geological Survey of Canada. The Flight Research Laboratory of the National Research Council of Canada, and the University of Calgary's Department of Geomatics Engineering assisted in the feasibility study and algorithm design. The National Research Council of Canada supported the research through IRAP Grant 22711U.

Corresponding author: info@sgl.com