Realistic potential field survey simulation to test survey design, sensor package, target resolution and processing systems

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SUMMARY

Realistic simulation of airborne magnetic and gravity surveys provides a low cost method for evaluation of survey design, new instrument types and processing procedures in a fully controlled test environment. A survey simulation system allows us to test survey design parameters, new or proposed sensors in different geological environments and answer questions on detection limits at predetermined noise levels. New processing procedures such as levelling, enhanced gridding, equivalent source reduction, rugged terrain compensation and FFT processing methods can be tested in a controlled geological environment before being applied to field surveys, where the geology is only partially understood.

The components of a realistic system include simulation of the survey aircraft, instrument sensor package, terrain and geology. The recent publication of the NASA, SRTM 90 metre spatial resolution digital terrain data for all continents and islands, makes it possible to place a simulated survey in any desired location. Combine this with a model of the flight characteristics of the aircraft and you can simulate the probable behaviour of the aircraft in the chosen terrain. From this model we can then generate a synthetic survey flight path with x,y,z samples and lines at any desired sample interval.

Geological model simulations include full tensor gravity, full tensor magnetic, total magnetic field lateral gradiometer, total magnetic field vertical gradiometer, fluxgate and total field surveys. The outputs of these simulated surveys can be used to determine optimum survey design, estimate detection limits for different survey/instrument packages, test new processing procedures and test proprietary processing algorithms against a predetermined geology.

Key words: aeromagnetic, potential fields, magnetic, gravity, modelling, gradiometry.

INTRODUCTION

The simulation of an airborne geophysical survey that can model a range of sensors, realistic aircraft behaviour over a known terrain with simulated geology can provide many valuable outcomes for explorers and service companies. Many problems can be resolved prior to the commissioning of expensive surveys. Survey simulation can be used operationally to anticipate field problems such as access issues in populated areas, excessive ground clearance for a specific aircraft, preferred flight patterns and the location of tie lines.

A survey simulation system requires the following components:

- Digital elevation grid
- Survey specification
- Aircraft performance model engine
- Survey generation (line,x,y,z)
- 3D geological model
- Sensor package model engine.

The only data required to produce the final product is the digital elevation grid.

The recent availability of the global coverage from the Shuttle Radar Topography Mission courtesy of NASA (2004), allows us to plan a survey anywhere in the world from the Andes to remote Pacific islands.

Geological models can be introduced into the terrain to test a wide range of exploration and mapping objectives. Targets with variable density and magnetic susceptibility can be buried to test detection limits of different sensor packages or provide valuable control data sets for testing new processing procedures.

SURVEY FLIGHT PLANNING

Digital terrain models can be obtained from many different sources including stereo photography, government data and the global coverage of SRTM data. The precision of the data source will place practical limits on deductions that can be made from the simulated surveys. The example below was produced from high resolution aerial photography and high resolution elevation data.

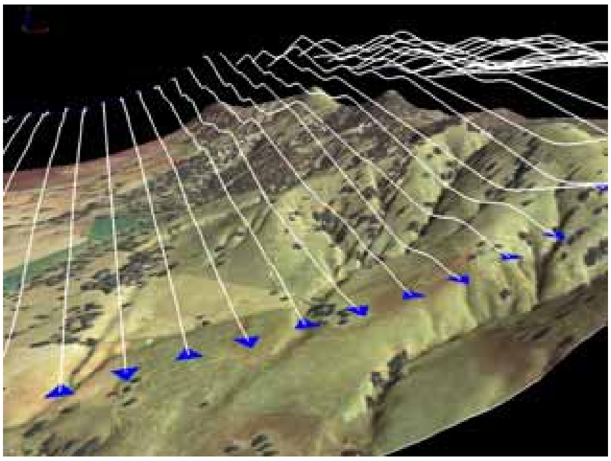

Figure 1. Example 3D display of a simulated flight path with an aerial photo draped over a digital elevation model.

The simulator needs to manage different flight patterns to accommodate both practical field conditions and geological parameter testing. The figure below shows some basic flight path configurations.

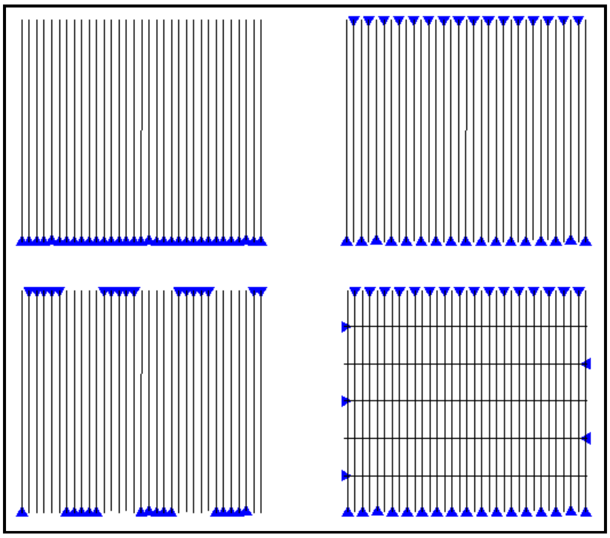

Figure 2. Examples of simulated flight line directions needed for realistic construction of survey models. The examples show constant, alternating, racetrack and tie line configurations.

Aircraft characteristics

A simulation model was developed that could produce a realistic flight path based on an airborne survey specification and the performance characteristics of the designated aircraft. The figure below illustrates some of the essential terrain characteristics that must be handled by the aircraft simulator.

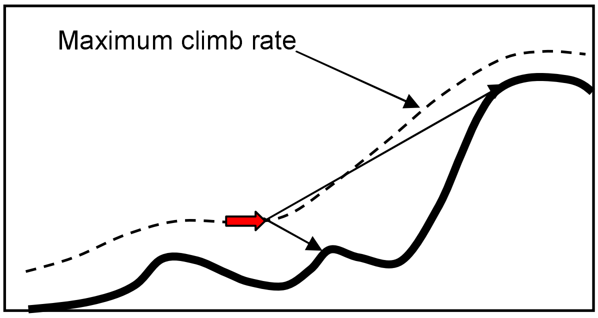

Figure 3. Illustration of the short and long look-ahead distances needed for accommodating the maximum aircraft climb rate.

The model uses the following characteristics to compute the elevation of the aircraft along the proposed flight path:

- Nominal survey clearance
- Minimum acceptable clearance
- Survey speed
- Near field look ahead distance
- Far field look ahead distance
- Maximum climb rate
- Maximum descent rate
- Maximum climb rate acceleration
- Maximum descent rate acceleration

The last two parameters require some experimentation to match pilot behaviour and the rest are accessible from the aircraft specifications. The following figure illustrates the impact of different flight directions over a 100 metre high cliff where in this example adjacent flight lines may differ in clearance by as much as 30 metres. With a nominal terrain clearance of 40 metres, there is a large impact on magnetic and gravity anomaly amplitudes for targets at the ground surface.

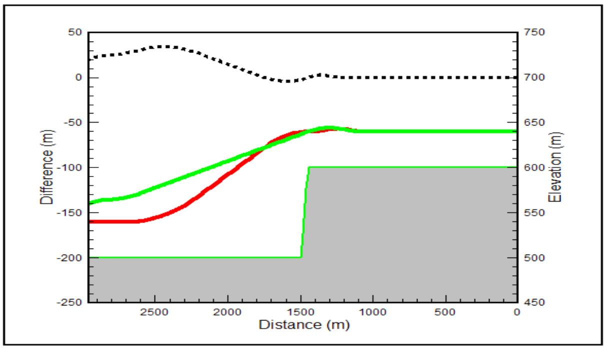

Figure 4. Simulation of vertical flight path for opposing flight line directions over a 100m cliff

The terrain model in Figure 1 was used to truncate a north-south oriented dyke with uniform magnetic properties. A 3D view of the combined model and semi-transparent terrain surface is shown in Figure 5a.

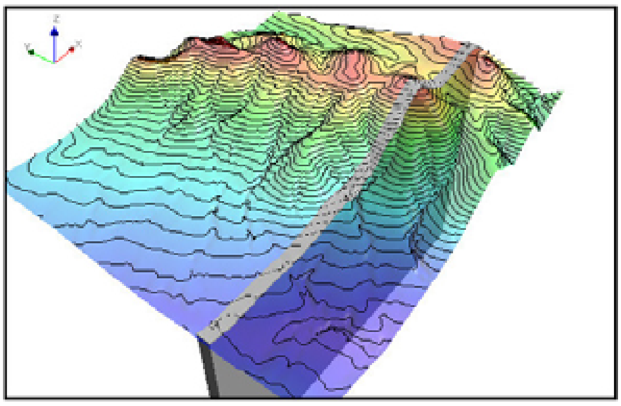

Figure 5a. Simulation model of a uniform dyke truncated by the terrain surface illustrated in Figure 1.

The total magnetic field intensity was computed for an east-west survey flown with a nominal 80m terrain clearance, 100 metre line spacing and alternating heading direction. The survey lines were then gridded using a 25 metre mesh and the results along the northern segment of the dykes are shown in Figure 5b.

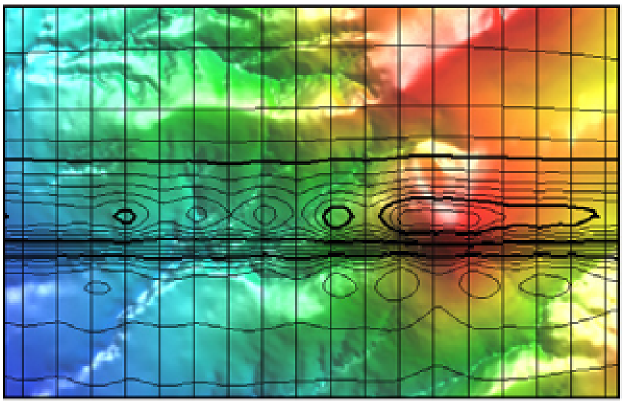

Figure 5b. Contours of the gridded magnetic data from the simulated alternating heading direction survey superimposed on a pseudocolour image of the terrain. The contour closures result from variable terrain clearance over the dyke.

INSTRUMENT SENSOR SIMULATION

Magnetic and gravity sensor systems are becoming increasingly complex and simply flying a survey over a test area cannot possibly answer all the questions relating to the merits and disadvantages of these new systems. The figure below illustrates a simulation along the synthetic flight path for a range of sensor systems.

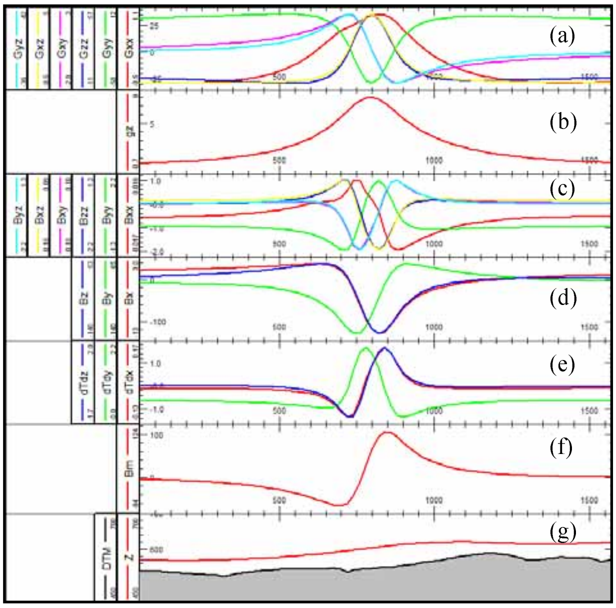

Figure 6. A comparison of sensors over the dyke shown in Figure 5 showing the gravity tensor (a), Gz vertical component of gravity (b), magnetic tensor (c), magnetic components (d), total magnetic field gradients (e), total magnetic field (f) and flight path over terrain (g).

Total magnetic field surveys are by far the most popular magnetometer systems in routine production. With the addition of wingtip sensors it is possible to compute the cross-gradient (dT/dx) and the longitudinal gradient (dT/dy) of the total magnetic field. Some systems allow for measurement of the vertical gradient of the total magnetic field (dT/dz).
Fluxgate magnetometers measure oriented components of the magnetic field which are normally translated to a Cartesian framework to provide Bx, By and Bz. The vector information has special advantages at low magnetic field inclinations and for remanence modelling. The major disadvantage of these systems is the sensitivity to slight orientation errors.

New instrument packages based on SQUID sensors are being developed to measure the magnetic tensor Bxx, Byy, Bzz, Bxy, Bxz, Byz where the notation "xx" implies the gradient of the "x" oriented magnetic field component in the x direction and "xy" implies the gradient of the "x" component in the "y" direction. These sensor packages offer extreme sensitivity to small gradients of the magnetic field and have special merits for off-line detection of targets, modelling of remanence and edge detection in low magnetic field inclinations.

Airborne gravity and gravity gradiometer surveys are also being used in a range of mineral exploration related activities.

GEOLOGICAL MODEL DEVELOPMENT

Geophysical modelling of geology is often thought of as an interpretation procedure, but it is also appropriate for use as a planning and testing method. The ability to simulate a practical airborne survey over a known terrain also makes it possible to simulate the geophysical response of a target embedded within that terrain. By using realistic aircraft behaviour, we have a way of adding noise that must be removed in conventional processing.

The 3D example below is used to illustrate some of the problems encountered in rugged terrain such as the Andes in South America. Adjacent lines can exhibit significant variations from the surrounding terrain and the relative vertical separation of adjacent lines can show high variability.

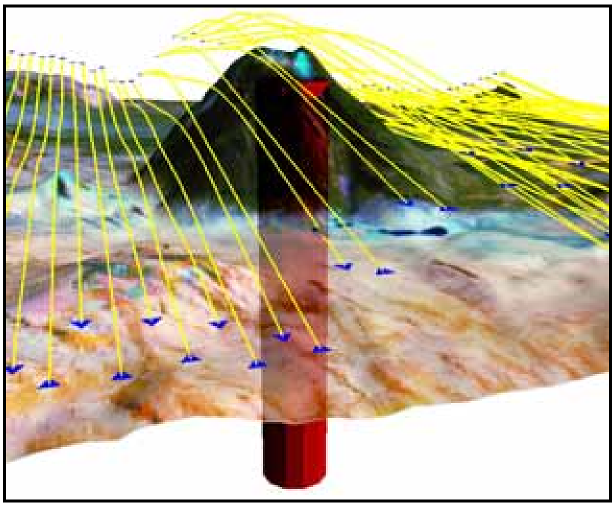

Figure 7. Simulated 200m line spacing survey and model in rugged terrain over a 1 km high volcano in the Andes, Chile.

The following survey classes are considered as part of the realistic modelling exercise:

- Flat earth survey
- Simple terrain model
- Rugged terrain model
- Rugged magnetic terrain model

Flat earth surveys can often be used to approximate magnetic surveys in low topographic relief because a constant clearance survey will only show minor differences in the simulated magnetic field over the equivalent flat earth model.

The following two examples were designed to test the presence of an igneous core within the central volcano-clastic pile. While it may be possible to distinguish the two end members through full 3D modelling, the levelling of the data presents significant challenges.

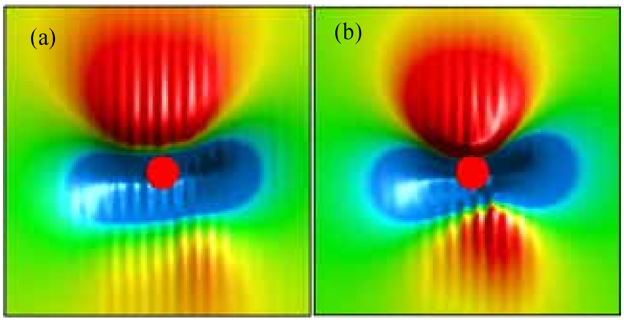

Figure 8. Simulated response of a central igneous core to the 1km high volcano where model (a) does not extend above the background terrain and the second model cores the volcano almost to its summit (b).

PRACTICAL OUTCOMES

There are many challenges for airborne potential field methods that remain unresolved and survey simulation can play an important role in the development of new techniques. Methods of particular interest include:

- Survey planning
- Testing of processing procedures
- Target resolution testing
- New instrument simulation.

Survey planning

New surveys can now be planned with realism using freely available global terrain and satellite image data. The example from Chile was compiled from the SRTM digital terrain dataset and satellite imagery from a global Landsat 7 TM compilation (Earth Resource Mapping, 2004). The simulation can be used by airborne survey contractors to prepare a realistic smooth survey envelope.

Testing processing procedures

Many software testing procedure are applied directly to field surveys where the correct answer can only be determined in a cosmetic sense. Simulated surveys over geological models in rugged terrain will produce a precise result that can be used for the development of new processing systems such as equivalent source levelling and improved gridding techniques.

Target resolution testing

With a wide variety of choices for instrumentation, survey aircrafts and operational techniques, how can an explorer determine which system will provide the best survey outcome that can be balanced against the various survey costs? Simulation of the geological target with the different methods allows the various systems to be tested in an objective manner. Examples include weak signals from mineral sand deposits, fault displacements at depth, extensions to known deposits in rugged terrain, kimberlite pipes of varying size and magnetisation.

Instrumentation design requirements

Survey contractors and instrument developers are experimenting with new systems all the time. There are practical issues with the installation, testing and processing of new systems. Realistic simulation provides a method for practical testing of new instruments well before they are built or installed in an aircraft. A current example is the development of the full tensor SQUID magnetometer and airborne gravity gradiometers.

CONCLUSIONS

Realistic airborne survey simulation is an important geophysical tool for explorers, survey contractors and consultants that allows objective decision making on the optimum choice of instrument package and survey design.

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REFERENCE

Earth Resource Mapping (2004) World mosaic - Landsat 7 mosaic with RGB742 band configuration, web site http://www.earthetc.com/.

NASA (2004) Shuttle Radar Topography Mission web site, Jet Propulsion Laboratory, http://www2.jpl.nasa.gov/srtm/