The growth of airborne gravity gradiometry – and challenges for the future

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This paper was prepared for presentation during the 12th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 15-18, 2011.

Abstract

In recent years there has been a continuing and growing interest in airborne gravity and gravity gradiometer capabilities. This attention implies both that significant achievements have been realized and that we have not yet arrived at the optimal capability – and that the process continues to find even better solutions. Advances in sensor systems, operational efficiency, data processing, and interpretation have all contributed to improved offerings to the market. Acceptance and interest by industry is evidenced by the numerous focused workshops, publications, and investment over the past decade. The prospect for greater usage is tempered a bit by the lack of definitive success stories and relatively high cost. The future for airborne gravity is also clouded by a number of questions: How much does airborne gravity help achieve the ultimate objective of finding more resources? What is the value of information (VOI) to the commercial market? What is lacking in order for airborne gravity to achieve full potential? With a view towards the future, it is also instructive to ask, "Where will airborne gravity be in five or ten years?"

Introduction

System Deployments

There has been a steady growth in the number of airborne survey providers and the total usage in the market over the past few years (DiFrancesco, 2010). Airborne gravity service providers now number at least 10 companies worldwide, with an estimated 45 systems in use. These gravity systems include the Sander Airborne Inertially Referenced Gravimeter (AIRGrav) system (Sander, 2010), Canadian Micro Gravity's GT-1A and GT-2A meters (Olson, 2010), Micro-g LaCoste TAGS Air III gravity meter, the Russian Chekan-AM mobile gravimeter, and a few LaCoste & Romberg dynamic gravity meters. It is estimated that nearly 1.1 million line-kms are flown on an annual basis for mining, hydrocarbon, and mapping interests. Additionally, airborne gravity gradiometer service providers today include ARKeX Ltd., Bell Geospace Inc., and Fugro Airborne Surveys Ltd. These companies have deployed gradiometer systems as follows:

ARKeX: 3 Full Tensor Gradiometer (FTG) systems, currently installed on Cessna Grand Caravan and De Havilland Twin Otter aircraft. Marine surveys are also being conducted using the ARKeX FTG.

Figure 1. ARKeX deployed gradiometer systems.

Bell Geospace: 3 Full Tensor Gradiometer (FTG) systems, currently installed on Cessna Grand Caravan and Bassler BT-67 aircraft. Also, the historic Zeppelin Airship deployment in South Africa and Botswana was a joint effort of Bell Geospace and DeBeers.

Figure 2. Bell Geospace deployed gradiometer systems.

Fugro Airborne Surveys: 4 Airborne Gravity Gradiometer (AGG – partial tensor) systems incorporated in the FALCON™ offering, installed on Cessna Grand Caravan and CASA C-212 fixed-wing aircraft, and a Eurocopter AS350 helicopter (Dransfield, 2010).

Figure 3. Fugro Airborne Surveys deployed gradiometer systems.

It is estimated that the total gravity gradiometer survey line-kms flown by these companies is on the order of 300,000 per year.

Technology Developments

Many development projects are underway around the world seeking to provide alternative capabilities to the presently-deployed gravity gradiometer sensors (DiFrancesco, 2008). These projects include:

- AOSense Atomic Interferometer (AI) gravity gradiometer
- ARKeX Exploration Gravity Gradiometer (EGG)
- GEDEX High Definition Airborne Gravity Gradiometer (HD-AGG™)
- Gravitec Ribbon Sensor Gravity Gradiometer
- University of Twente MEMS gravity gradiometer
- University of Western Australia VK-1 gradiometer

These developments have required a significant amount of investment - on the order of $50M (USD) since 2005. This financial commitment represents another measure of growth and interest in the field of airborne gravity. As a result of these activities, over 45 worldwide patents have been granted since 2004 for technological advances in the areas of gravity sensor design, data processing, and survey operations.

Industry Interest

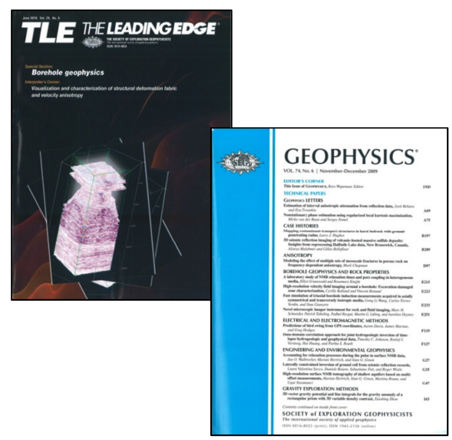
Another indicator of the 'state of gravity' is the number of workshops and publications that have been focused on the topic of gravity. Since 2004, there have been many symposia, special sessions, and workshops hosted by geophysical societies around the world with the objective of promoting gravity capabilities. Some of these sessions include:

- SEG's "Gold Workshop" in Denver, CO in 2004.
- EAGE's "EGM 2007" and "EGM 2010" meetings in Capri, Italy.
- SEG's "Gravity in Motion" workshop in Las Vegas, NV in 2008.
- EAGE's "EM, Gravity and Magnetic Technologies – Their Impact when Integrated with other Geophysical and Geological Data" workshop in Rome, Italy in 2008.
- EAGE's "The Future of Non-Seismic Methods" workshop in Bahrain in 2008.
- SAGA's focused track on gravity gradiometry at the 2009 meeting in Swaziland.
- EAGE's "Advances in High Resolution Gravity and Magnetics – Case Studies" workshop in Barcelona, Spain in 2010.
- ASEG's "Airborne Gravity 2010" workshop in Sydney, Australia in 2010.
- SBGf's Forum "Non Seismic Methods: Birth and Re-Birth of Geophysics" held in Rio de Janeiro in 2010.

Finally, a search through the leading trade journals in geophysics reveals a growing number of publications and articles on the topic of gravity surveys and methods. Since 2004, the leading geophysical societies have published articles on airborne gravity as follows:

- **EAGE** (including *First Break, Near Surface Geophysics* and *Geophysical Prospecting*): a total of 129 articles and extended abstracts

- **SEG** (including *The Leading Edge* and *Geophysics*): a total of 58 articles



- **ASEG** (including *Preview* and *Exploration Geophysics*): a total of 23 articles

The Significance of Gravity

Value of Information

Typical airborne gravity surveys today cost between $40 and $70 (USD) per line-km, depending on survey size and other logistic factors. Airborne gravity gradient surveys are even higher, on the order of $130 to $175 (USD) per line-km. Based on the previous stated annual estimates of 1.1M line-kms for airborne gravity and 300,000 line-kms for gravity gradiometry, this represents industry revenues of $44M to $77M (gravity) and $39M to $53M (gradiometry). Another way of saying this is that exploration budgets must include appropriations between $83M and $130M simply to sustain current activity for airborne gravity and gradiometry. Is this sustainable? Is there growth in these numbers? Is the value received from these expenditures commensurate with the outlay? These questions can be answered in less quantitative ways by asking the following questions:

- Are repeat customers coming back for more survey work?
- Are new customers emerging as capability is demonstrated?
- Are new customers waiting for advances (technically, operationally, answer products, etc.) before committing?
- When given a choice, are potential customers spending their limited exploration budgets on other things?

Other Opportunities

While resource exploration is the prime focus for airborne gravity activity today, looking at adjacent opportunities provides for interesting consideration. For example, gravity and gradiometry are well suited for many near surface applications such as civil engineering, environmental monitoring, water detection, tectonic monitoring, and earthquake prediction (Hodges, 2010). Will growth into these areas provide a significant upside for current practitioners? Will it open doors for newer developments? If growth is to be achieved in the application of airborne gravity, then new prospects will need to be vigorously pursued.

Airborne Gravity in the Future

Strategy and Innovation

A recent presentation by Dr. Vijay Govindarajan from the Tuck School of Business at Dartmouth University highlighted a number of key items for consideration as strategy and growth plans are considered (Govindarajan, 2010). Strategy can be defined as “innovation” and “next practices.” In other words, it involves moving beyond what is known and comfortable and expanding into new constructs and ways of doing things. Essentially, we all have two current responsibilities: (1) make money for today, and (2) plan for making money in the future. An approach for pursuing these objectives can be broken into three parts: (1) manage the present, (2) selectively forget the past, and (3) create the future. One of the things that can hinder growth and progress is being wed to the past. “We’ve always done it this way” is a common refrain in any industry. An example of innovation in a totally different field can be seen in the advances made by Olympic high jumpers during the 1900’s. Innovation in jumping methods, then improvements within the method, yielded great improvement. Each step change in advancement was the result of an innovation in style. Figure 4 shows the progression in achievement from the scissors style to the western roll to the straddle to the Fosbury flop – with this latest convention accepted as the benchmark for excellence. While the relevance to resource exploration progress may be a stretch, the point is that innovation and advancement happens as the result of the need to improve. If we look back on the exploration industry, we can see that things have indeed progressed over the years. Since the first gravity experiments in the 1600’s to today’s airborne gradiometer systems, innovation has been the catalyst for progress. Airborne gravity was first introduced in the late 1950’s. It has progressed to the levels of exceptional performance today by virtue of moving forward and building upon success. (Hatch, 2010) Airborne gravity gradiometry surveys only started in 1998, and since those early efforts we can see continual improvement (see Figure 5). So, we aren’t doing things the same way as we did in the 1950’s – or the 1990’s. The question is, “What should we be planning for in the decades ahead?” What will airborne geophysical exploration look like in 2025? In 2050? We would expect that there will be an increased demand for commodities as population grows and countries/economies develop. This will necessitate a continuing need for exploration to find new resources to support the growth. Can we assume that the way we do things today will be adequate to meet the demands of tomorrow?

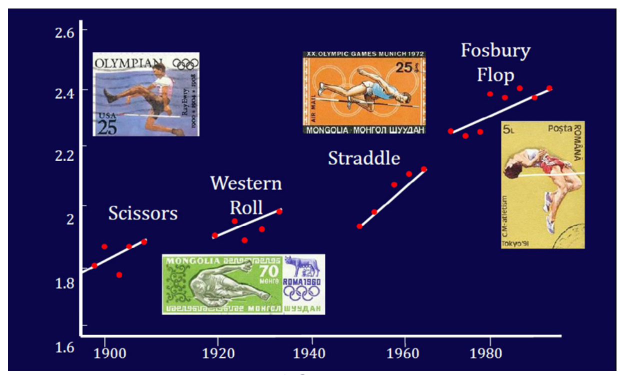


Figure 4. Advancement of Olympic high jumping achievements.

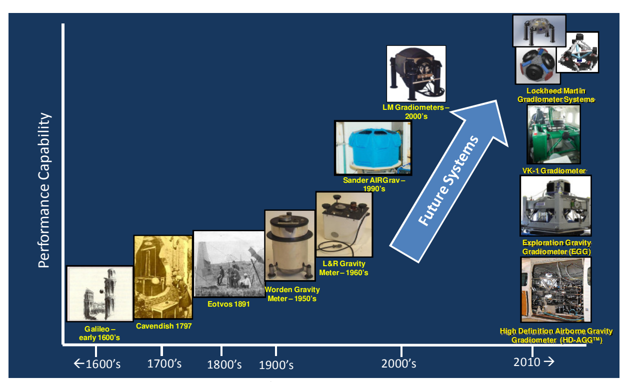


Figure 5. Progression of gravity measuring capability over the past centuries.

The Future of Airborne Gravity

A few final thoughts are provided on the expected growth in gravity capability and acceptance. This process is in reality an act of seeking. It could be called a search, pursuit, investigation, mission, hunt, or expedition. In any event, it involves the act of looking ahead. So, we should ask questions that will be directive to help us reach our destination. What will exploration look like in 2015? In 2025? In 2050? If I am pressed to predict or forecast how the future will look, here are some of the key elements I would include (DiFrancesco, 2009):

1. Airborne surveys will be flown at faster speeds and coverage rates and in higher dynamic conditions.
2. Scalar gravity and gradients will be measured with greater precision than available today.
3. Survey costs for airborne gravity will be significantly lower.
4. Integrated scalar gravity plus second and third order tensor gradient data will be available in a single service offering.
5. Gravity (scalar and tensor), along with both magnetics and EM, will be configured on the same survey aircraft and an economy of scale realized.
6. A series of significant exploration successes will be attributed to gravity and gradiometry.
7. The market will really understand what gravity and gradiometry can do for them.

Conclusions

It is readily apparent that airborne gravity is becoming a mainstay of the exploration industry. Technical and operational advances in the past few years have enhanced the capability, and there is a foundational acceptance for the benefits of these techniques. A growing understanding of gravity benefits and utility is being communicated to the market in the form of workshops, technical publications, and first-hand experience. It is also clear that the way things have been done in the past will not support the needs for the next generation of explorationists. New technology, new approaches, and out-of-the-box thinking will be necessary to keep airborne gravity relevant and lead the charge to further exploration success.

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