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RECENT ADVANCES IN HIGH RESOLUTION AEROMAGNETICS – INSTRUMENTATION

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ABSTRACT

The last decade has seen a revolution in the quality and resolution of the equipment available to the exploration geoscientist for conducting airborne geophysical surveys. While the basic, underlying science of physical rock property measurement has remained unchanged, and no radically new sensor systems have been added to our toolkit, the fidelity with which these physical rock property parameters can be recorded has increased enormously. At the same time, the methodologies employed to collect this data have changed, with surveys being flown so as to significantly increase the density of data measurement coverage.

This revolution has been caused primarily by advances in computer technology and power, and by miniaturization of electronic components. Airborne systems are now capable of recording Gigabytes of data about every aspect of a geophysical sensor and about the aircraft's position and attitude. We can now measure every movement of the aircraft and deconvolve the aircraft's magnetic effects from that of the Earth's, yielding measurement accuracies of 0.01 nT; one or two orders of magnitude better than what was typical in 1987. We can also position that measurement to an accuracy of a few metres in x, y and z, using the new satellite based Global Positioning System (GPS).

INTRODUCTION

The new fidelity in measuring physical rock properties, in air borne surveys has sparked philosophical changes in how we plan and conduct surveys. If we can now measure so much more detail, how much more information can we obtain if we fly lower, slower and with tighter line spacing? New classes of rock properties become visible; not seen before due to the poorer "eyesight" we had 10 years ago. A topical comparison is the new classes of astronomical information detected by the Hubble Space Telescope after it received its new "eyeglasses".

Table 1. Advances in Data Acquisition.

TECHNOLOGICAL ADVANCES	PHILOSOPHICAL ADVANCES
• Magnetometers	• Tighter Traverse Line Spacing
• Acquisition Systems	• Lower Tie: Traverse ratios
• GPS Positioning	• Lower Altitudes
• Aircraft Compensation	

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Table 2. Advances in Data Processing.

TECHNOLOGICAL ADVANCES (Processing)	PHILOSOPHICAL ADVANCES (Presentation)
• Computer Power	• Image Presentations
• Leveling Techniques	• GIS Presentations
• Enhancement Filters	• Interpretation Techniques

This wealth of added information about geophysical parameters was further enhanced as the data processors started to re-work all of their programs to more accurately reflect the geophysical theory on which the programs were based. The rapid boost in computer power available to the programmer allowed new algorithms which took less short cuts in calculating the lengthy equations that took physical measurements to understandable data and maps. This boost in computer power also gave us Image Processing and GIS capabilities, each of which showed us even more information hiding in our data.

This process of constant incremental improvement continues, with processing and acquisition leap frogging each other, spurring new advances at a rapid pace.

Magnetometers

Cesium vapor magnetometers are the type most widely used for aeromagnetic surveys and for base stations, whenever the highest resolution and/or cycling rates for measurement of the Earth's magnetic field is required.

Table 3. Magnetometers

	New	Old
Type:	Optically Pumped Cs, He	Proton Precession
Resolution:	0.001 nT	0.10 nT
Noise Envelope:	≤ 0.1 nT	≤ 1.0 nT
Sample Rate:	10 Hz +	1 Hz

The output of a cesium sensor is essentially continuous in practice. Combined with the necessary electronics, it can operate at a resolution of up to 0.001 nT at sampling rates of up to 10 readings per second, throughout a range of 20,000 to 100,000 nT.

The magnetometers can be installed in fixed-wing aircraft or helicopters, in either "stinger" or "towed bird" configurations, and, in addition to measuring total magnetic field, can be used to make vertical, transverse and/or longitudinal gradient measurements by using two or more sensors (see Fig. 1).

A typical cesium magnetometer installation comprises some or all of the following subsystems:

- Sensor
- Orienting Gimbal
- Signal Processor and/or Compensator and
- Airfoil

Aircraft Motion and Attitude Sensors

With the increased computer power available both on the aircraft, and for post-flight data analysis, we are now able to make good use of platform motion measurements to deconvolve the artificial anomalies created by the aircraft, from anomalies created by geologic variations.

When a magnetometer is installed in a fixed-wing aircraft, typically in a tail stinger, it is necessary to compensate the magnetometer for the fact that the aircraft itself creates different magnetic effects when it is in different orientations with respect to the Earth's magnetic field vector. A decade ago it was common to use a compensation system which mechanically corrected for the effect of the aircraft. These systems utilized special magnetic materials mounted near the sensors to offset the effect of the main body of the aircraft or, used Helmholtz coils surrounding the sensors to "buck out" the aircraft's magnetic field. Systems in use today simply record in detail all of the relevant magnetic and aircraft-motion data, and use software programs to re-create the magnetic field that would exist if the aircraft was not present.

The basis of these automatic software compensators is the correlation of the motion noise on the magnetometer with the pitch, roll and yaw (and rates of change of these elements) of the aircraft. Permanent, induced and eddy current effects are compensated by this method, as are the residual heading effects of the individual magnetometer sensors. A set of algorithm co-efficients is derived which, when applied to on-survey-line data, serves to separate the effect of the aircraft from the effect of local geology.

The attitude and motion of the aircraft in flight, with respect to the Earth's magnetic field vector, is monitored by a three-component flux-gate magnetometer which is very sensitive to attitude changes. The outputs of this magnetometer, or motion sensor, are used in the mathematical computations on the raw magnetic data to produce the compensated magnetometer or gradient data. This set of PC-based programs can be used for both real-time and post-flight compensation of the raw magnetic data.

With towed bird systems, more and more operators are using pitch, roll and yaw detectors in the bird to correct for geometric errors created as the bird departs from its assumed ideal flight orientation.

Navigation and Positioning

Global Positioning Systems, or GPS, are the ultimate in navigation and positioning systems for aerial surveying. GPS is a system which provides accurate positional information based on signals received from a constellation of 24 satellites. GPS is a system that has been developed by the U.S. Department of Defense for military use. Glonast is the equivalent Russian system.

GPS brings a number of important benefits to aerial surveying. Firstly, the coordinates of the survey aircraft (horizontal and vertical) are provided on a continuous basis. This not only improves the quality of survey navigation and reduces its cost, it also simplifies data compilation and presentation by eliminating, to a large degree, the tedious and error-prone manual steps inherent in flight path recovery from film or video. Secondly, GPS provides a reusable positioning system. Surveys flown at different times in the same area may be precisely correlated in position, making it easy to repeat survey lines or to fly gap-filler lines.

Modern navigation systems have the ability to present the entire survey area, complete with the desired flight path grid, as a graphic Moving Map display, with the position of the aircraft being continuously updated and plotted on a screen, as it proceeds along the flight line. Additionally the system provides a steering indicator to assist the pilot/navigator to "steer" accurately along the proposed flight-line. This display is continuously updated and displays numeric information such as: heading, latitude and longitude or UTM coordinates, cross track, line number, ground speed, distance to go, GPS time, PDOP (data quality), GPS altitude, and more.

More recent innovations have added the third dimension to the navigational instructions presented to the pilot. In these systems, a pre-programmed digital terrain map is compared to the real-time GPS derived elevation and climb/descend instructions are given to the pilot, in addition to the customary left/right instructions. 3D navigation has proved itself to significantly improve the quality of data collected in rugged terrain, by minimizing height variations between adjacent flight lines, and at the tie-traverse crossover points.

The true accuracy of the position obtained with a GPS receiver is dependent upon the equipment used. Stand-alone, or autonomous, GPS sensors are subject to "Selective Availablity" (SA), a process whereby the US military owners of the network can "selectively" reduce the accuracy of an autonomous GPS receiver at will. This is done for national security purposes. Most survey operators get around this degradation of signal by using a process of "Differential Correction" of the aircraft's recorded GPS position. Through the acquisition of GPS data from a stationary base, and an analysis of the apparent "movement" of this non-moving location, a correction factor is developed which can be applied to the aircraft GPS, thereby reversing the effect of SA. This can be done in real-time, or post flight. The resultant accuracy's are typically in the order of a few metres of true location in x, y and z. This capability has significantly enhanced the accuracy with which our

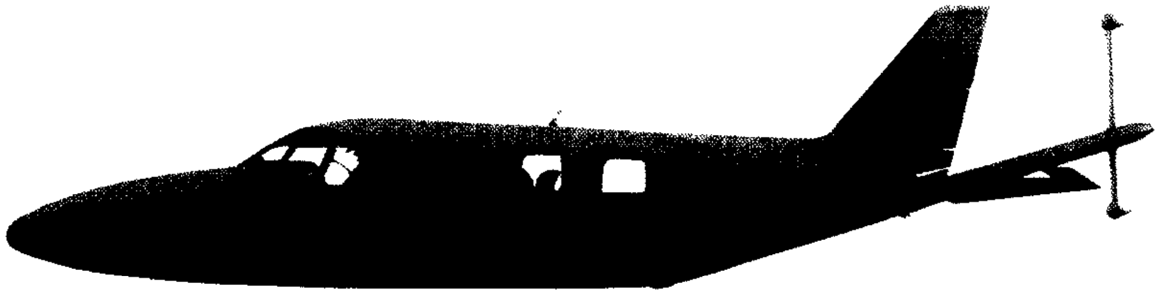

Fig. 1.

data measurements can be located, and therefore the resolution with which the physical rock property variations are located. Hence, all derived geological interpretations are also much enhanced in resolution and accuracy.

Data Processing – Key Advances

The result of these new data acquisition capabilities and procedures is that we now provide to the data processor a significantly higher-resolution, and better positioned, magnetic data set. The processor can in turn do much more with the data set, due in part to the significantly higher amount of computer power at his disposal, and in part due to new concepts being employed in the treatment and presentation of the data.

The first thing done with any new data set received from the field operation is to check for noise; high-frequency instrumentation noise, and mid-frequency aircraft compensation noise. The former is analyzed using a fourth-difference operator, while the latter is analyzed using a first derivative enhancement. Line-direction and flight-grouping patterns are noted, and correlated to potential problems with the aircraft systems and with the derived compensation co-efficients. Lines or entire flights with poor system operation or poor compensation are readily highlighted with this procedure.

The magnetic base station data is then checked for noise and diurnal variations beyond the tolerances agreed upon with the client. New survey procedures typically require a tie-line:traverse-line spacing ratio of 4 or less, which, when combined with the tighter line spacing parameters in use today (250 metres is quite common), has the aircraft crossing a tie:traverse intersection roughly every 15 seconds. What this means is that long wavelength diurnal variations are not anymore considered a problem, and most modern diurnal specifications limit only the high frequency variation from a linear mean equaling the average tie line interval.

We then employ statistical analysis of the tie:traverse cross-over grid to create a "leveling surface", which, when applied to the field data, effectively removes the mid-to-long wavelength effect of the magnetic diurnal variation.

A final, and newly developed process, is termed Micro-Leveling. This is a very computer-intensive analysis of the high frequency, low amplitude variations residual in the tie-line-leveled data. These features are small effects typically caused by line-to-line altitude busts, minor compensation problems, or diurnal micro-pulsations. An along-line/across-line data correlation algorithm is used which suppresses features with no direct and immediate local cohesion within the data set. Care must always be taken that the final micro-leveling is done so as to avoid any degradation of the geologic content of the data.

The final result of these new processes is a data set which has a resolution and accuracy well below 1.0 nT and 5.0 metres.

Data Presentation – Key Advances

Once we have finalized the processing of our data set, a new suite of image processing tools allows us to extract the most from the data. Since we effectively have a three dimensional surface of data, we can view it as we view the world around us; with different sun angles, sun elevations, close-up views of small features, and far-back views of large features, from above, below or from any direction. All with the push of a mouse button, in real-time.

New algorithms also allow us to, among other things, frequency-slice the data according to the specific geologic frequency content inherent to data collected for that point on Earth. Each individual frequency slice can then be imaged as a distinct 3D surface. This again helps to identify small, obscure elements of the data that have always been there, but were hidden from view.

Conclusions

Many other geophysical sensors may be added to the basic magnetometer package discussed in this paper. Each of these complimentary technologies have themselves similarly advanced in resolution and capability over the last decade.

The net effect of these instrumentation advances has been the acquisition and presentation, of subtle geological effects which, with older technologies, were either not detected or, at best, were not obvious on the final data sets. Other papers will discuss how this new information can be put to use for assisting in the exploration for oil and gas reservoirs.