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Real Time Compensation for Aircraft induced noise during high resolution Airborne Magnetic Surveys

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ABSTRACT:
Typical Aeromagnetic survey requires fixing the magnetic sensor in a tail boom. For practical considerations, the tail boom can't be more than 10 to 15 feet long. As a consequence, there will be significant interfering magnetic field at the sensor due to the aircraft itself and also due to its maneuvers during flight. For high-resolution magnetic surveys, this interference is not acceptable. An instrument, called Automatic Aeromagnetic Digital Compensator (AADC), makes it possible to remove these interferences in real time to a very good extent. However, in lower latitudes cesium sensor enters into dead zone when aircraft maneuvers in certain directions, thereby making it impossible to obtain a single compensation solution that is valid for all four cardinal directions. Most of India falls into this category there by requiring careful calibration runs, which yield partial solutions for each cardinal direction. Proper combination of partial solutions is vital to get valid compensation solution. In this paper we describe the AADC, it's calibration procedure and discuss the criteria for choosing partial solutions to arrive at combined solution. Also, actual calibration and compensation flight data is discussed.

AUTOMATIC AEROMAGNETIC DIGITAL COMPENSATOR

Sources of interfering magnetic fields during Aeromagnetic surveys was identified and described by Lelik (1961). A mathematical model was derived which can be used to compute the interference as a function of direction cosines cos X, cos Y, cos Z and their time derivatives. Direction cosines are defined as:

$$\cos X = T/H_e$$
$$\cos Y = L/H_e$$
$$\cos Z = V/H_e$$

where H_e is the total field, T is the component of H_e along transverse axis of the aircraft (positive to port), L is the component of H_e along the longitudinal axis of the aircraft (positive forward), and V is the component of H_e along the vertical axis of the aircraft (positive down).

The model consists of about 18 interference coefficients, which are calculated at the end of the calibration flight and direction cosines are obtained by the fluxgate magnetometer during the compensation run.

Automatic Digital Compensator (AADC), designed by RMS Instruments, Canada, is based on the above described interference model. It accepts the Larmor frequency outputs of high sensitivity magnetometers, and produces magnetically compensated total field in digital and analog forms. AADC computes interference coefficients at the end of a calibration flight for which it gets the necessary inputs from a 3-axis fluxgate magnetometer. An interference model of up to 30 terms compensates for permanent and induced magnetism, Eddy Current effects, and for orientation errors in the magnetic sensors. These coefficients constitute a solution, which is applied during a compensation flight to get compensated total field in real time. Thus, the AADC provides real-time compensation of the interference caused by the aircraft or helicopter, as they maneuver in the earth's magnetic field. The AADC is capable of processing the magnetometer Larmor frequency signals to a resolution of 0.001 nT over a bandwidth of DC to 0.9 Hz without phase distortion. The compensator accuracy of the system is such that it allows the sensitivity of the optically pumped magnetometers, typically 0.003 nT p-p, to be fully realized.

PLACEMENT OF FLUXGATE VECTOR MAGNETOMETER

The Fluxgate Vector Magnetometer sensor must be rigidly mounted in a magnetically quiet location of the aircraft. This location should be as far away as possible from any sources of magnetic noise. This can be accomplished by placing the Vector Magnetometer at different positions and the output monitored on a chart recorder while the aircraft controls are moved. The location corresponding to the minimum interference should be selected for placement of the Vector Magnetometer. Very Successful compensations have been achieved using tail portion of the aircraft for stinger mounted sensor configuration.

CALIBRATION PROCEDURE

During the calibration mode, information is accumulated about the aircraft's magnetic properties for use during the compensation run mode. To carry out the calibration, the aircraft is taken to an area of known low magnetic gradient, to as high an altitude as operationally practical. The change in the total field over the area of calibration should be smooth, and the total change should be less than 200 gammas. An area south of Hyderabad (center point being N 16° 20′, E 79° 10′) has been identified as a suitable place meeting the requirement. A square pattern with sides in all cardinal directions and side equal to 10 nautical miles has been formed within the above identified magnetically low gradient area. Aircraft flew on this pattern at an altitude of about 10,000 feet with a speed of 140 knots. After entering the calibration mode, in each direction, aircraft was maneuvered to include ± 10° rolls, ± 5° pitches and yaws. Each maneuver took approximately 40 seconds, thus needing about 2 minutes for each direction. At the end of the calibration, a solution is calculated and its figure of merit is indicated. The solution obtained can be stored for using with compensation run mode. Fig.1 shows the flight path, as recorded by the on board Global Position System (GPS) with an accuracy of 25 meters.

As can be seen from Fig.1, aircraft flew twice in square pattern, as we had to calibrate two AADCs, in a single calibration flight. At low latitudes, say less than 30°, cesium sensor enters into dead zones when aircraft is flying in certain directions (Hardwick 1984). Thus, it is not possible to fly in a square pattern without encountering dead zones. Therefore, a single calibration solution, which is valid for all directions, is not possible. As a consequence, partial solutions should be obtained for each cardinal direction. These partial solutions can be stored in AADC's memory and can be used to generate combined solutions.

During the calibration flight, the total field should be monitored on the chart recorder (alternately, graphical trace can be monitored on the data acquisition computer) for switching transients. If any transient is noticed during the calibration maneuvers, the resulting solution will have poor figure of merit and should be discarded. In such a case calibration run should be repeated.

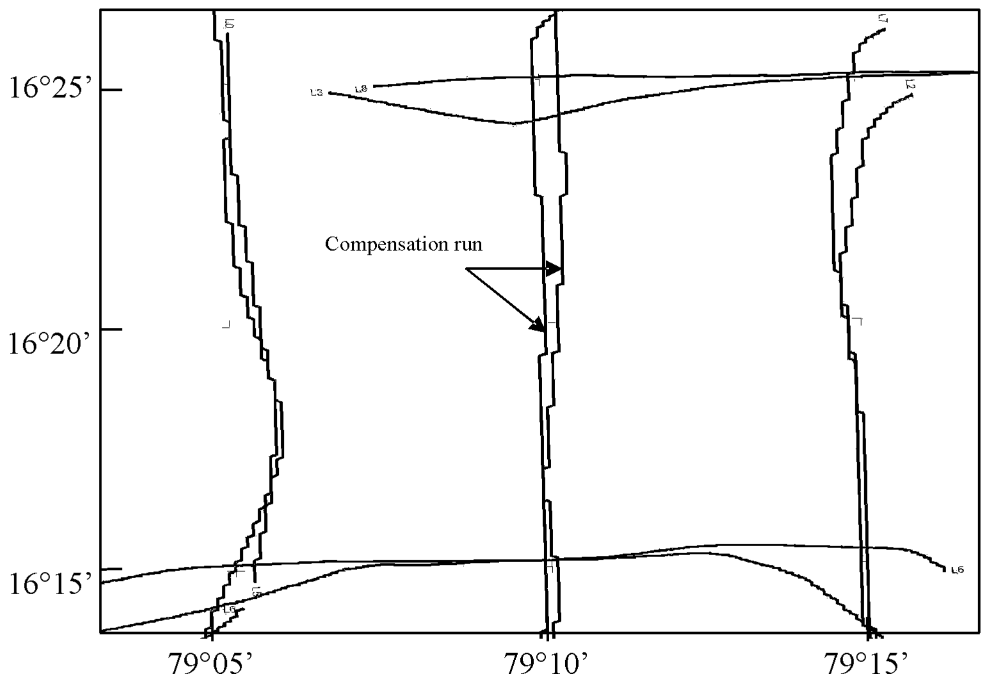

Figure 1. Flight path during AADC calibration and compensation runs. Double traces correspond to two AADCs under test. Calibration was carried out at 10,000 feet altitude. Compensation run was carried out on the north-south profile at an altitude of 400 feet.

VALIDATION OF CALIBRATION RESULTS

At the end of each calibration run, AADC computes two parameters, namely Improvement Ratio (IR) and Vector Norm (VNRM), which indicate the quality of the calibration. IR is defined as the ratio of standard deviation of uncompensated total magnetic field to the standard deviation of compensated total magnetic field. Typically IR value of 20 and above is desirable. Vector Norm gives an indication of difficulty of obtaining the solution. Typically this parameter is less than 100. Significantly higher NORM may indicate problems. Thus, calibration and resulting solution is valid or not is indicated by these two parameters.

CALIBRATION OF AADCs

We have installed Cesium magnetometer and Automatic Digital Compensator in a fixed wing aircraft, King Air B-200. Two identical AADCs, one belonging to N.R.S.A and second belonging to N.G.R.I, were carried onboard for testing as well as comparison. These two are designated as AADC#1, AADC#2 for further discussion. Area used for calibration and flight paths are shown in Fig.1. Two paths, in the figure correspond to the calibration of two AADCs. Uncompensated total magnetic field recorded in each of the four cardinal directions is shown in Fig.2 and Fig.3 corresponding to AADC#1 and AADC#2, respectively. The effect of aircraft maneuvers can be clearly seen as noise riding over otherwise smoothly varying magnetic field. In each cardinal direction each type of maneuver, namely roll, pitch and yaw, was performed three times. Except in south direction flight, we can clearly see nine cycles of aircraft induced noise on the observed total magnetic field. The aircraft induced noise during south direction flight is relatively very less in the case of both AADCs. The reason for this could be small amplitude maneuvers performed due to the prevailing flight conditions in that direction. The effect of this is poor IR ratio of 5.4 and 5.9 as shown in Table 1 for the case of south direction flight. For all the other directions, except west direction case of AADC #1, we obtained very good IRs and acceptable VNRMs. A close look at Figure 2d shows the presence of a large switching transient during 'pitch' maneuver in westerly direction. This switching transient occurred due to the activation of some hydraulic mechanism in the aircraft, nearly once in 6 to 7 minutes. We could attribute the transient to the hydraulic activation as the observed transients coincided with the loud sounds generated by the hydraulic mechanism. As expected, occurrence of transient during the calibration resulted in a very low IR of only 1.1 and very high VNRM of 10212, as can be seen in table1 for west direction flight in the case of AADC #1. Clearly, this solution is not acceptable and should not be used for obtaining combined solutions. This explains why the combined solutions, such as N+S+E+W and E+W, resulted in IR of only 1.1 in the case of AADC #1. On the other hand, combining north and south solutions yielded a solution with acceptable IR and VNRM for both the AADCs. In summery, the

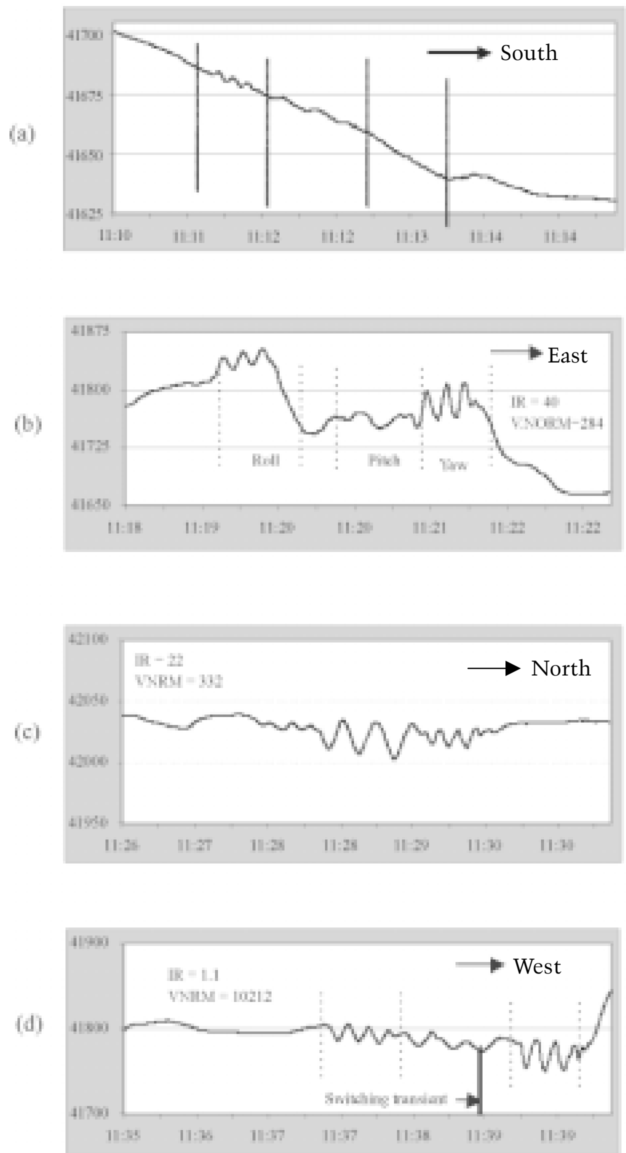

Figure 2: Calibration AADC #1. Profiles along 4 cardinal directions indicating effects of aircraft maneuvers.(X-axis is time, Y-axis is uncompensated total magnetic field in nT, X axis can be taken as distance of 10 km approximately)

calibration of AADC #1 is such that compensation runs can be carried out in north-south directions only using N+S solution. In the case of AADC#2, calibration is such that we can use the combined solution N+S+E+W valid for survey in any direction. Furthermore, it is advisable to repeat the calibration run for a particular cardinal direction if a severe transient is noticed in uncompensated total magnetic field anytime during calibration run in that particular direction.

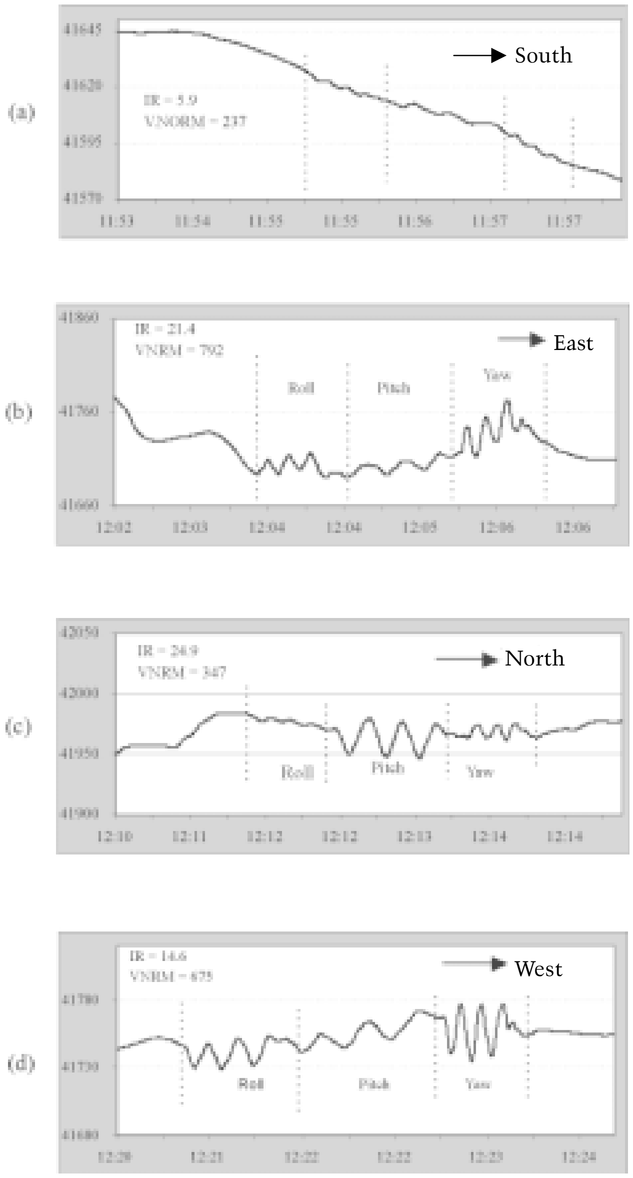

Figure 3. Calibration of AADC #2. Profiles along 4 cardinal directions indicating effects of aircraft's maneuvers (X-axis is time, Y-axis is uncompensated total magnetic field in nT, X-axis can be taken as distance of 10 km approximately).

Table 1: Calibration summery of two AADCs

	AADC #1		AADC #2	
	IR	VNRM	IR	VNRM
North	22.0	332	24.9	347
South	5.4	175	5.9	237
East	40.0	284	21.4	792
West	1.1	10212	14.6	675
N+S+E+W	1.1	574	14.4	230
N+S	16.0	226	17.0	238
E+W	1.1	1000	14.6	675

COMPENSATION RUN

For testing the effectiveness of compensation, AADC#2 was run in compensation mode with the solution obtained after the calibration mode. Aircraft flew on a North-South profile in both directions at a height of 400 feet. The uncompensated and compensated total field data is shown in Fig.4. It is very clear that the compensated data has almost eliminated the heading error of nearly 389nT. It also effectively removed the interference caused due to the maneuvers. Region I corresponds to North to South flight, region II during 180° turning and region III corresponds to South to North flight. Thus, region I & III are mirror images from the aircraft position point of view. Heavy fluctuation in region II is due to the dead zone encountered during turning.

CONCLUSIONS

AADC is an excellent tool to compensate in real time for the interference caused by the aircraft maneuvers during high-resolution Aeromagnetic surveys using fixed wing aircraft. However, proper calibration and judicious mixing of partial solutions is very important to obtain the proper compensation. Choosing magnetically low gradient area, monitoring total field for switching transients, performing well planned roll, pitch and yaw maneuvers, positioning the vector magnetometer etc. shall play an important roll in carrying out successful calibration of AADC resulting in good compensation runs.

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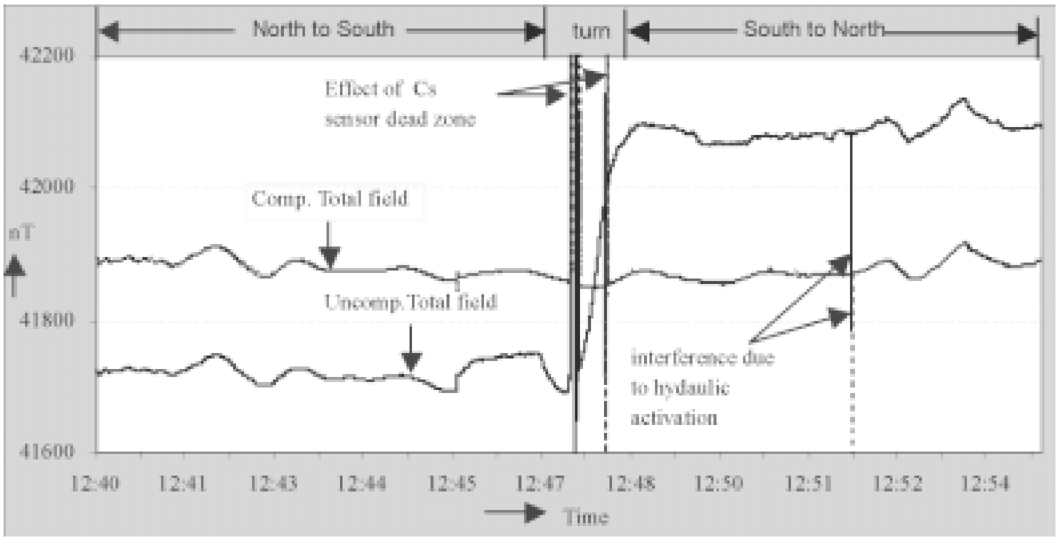

Figure 4. Compensated and uncompensated total magnetic field on a north-south profile. Aircraft flew first in south direction, took a turn and flew in north direction on the same profile. A large heading error can be seen on the uncompensated total field. Compensated total field is free from this error.

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