Designing and building an unmanned aircraft system for aeromagnetic surveying

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Summary

Carleton University, in collaboration with Sander Geophysics Limited, has developed an original design for an unmanned aircraft system (UAS) for aeromagnetic surveying, the GeoSurv II. A UAS has the potential of collecting higher resolution data compared to conventional aircraft due to its lower altitude flight capability. A first prototype of the GeoSurv II has been built. It is an all-composite modular aircraft of a twin-boom pusher configuration with a wing span of 4.88 m and a length of 4.27 m, and a maximum takeoff mass of 90 kg. This prototype will first be used for flight tests and later be instrumented with two Cesium magnetometers on the wingtips and a fluxgate magnetometer in the fuselage. Concurrently with the assembly of the prototype, a simulated UAS has been built. The simulated UAS is a modified magnetic bird towed beneath a helicopter. It features two magnetometers with the same separation distance as in the GeoSurv II design. A test survey was flown using the simulated UAS and the data acquired are compared with conventional regional aeromagnetic data collected using a fixed-wing aircraft.

Introduction

Aeromagnetic surveys are usually flown using manned aircraft such as Cessna Caravan at altitudes of approximately 100 m or more above ground level (AGL). Onboard crew will typically comprise a pilot and a co-pilot. An overall survey crew for a campaign in a remote area may be four or more persons, including an aircraft maintenance engineer. Aircraft need to be modified to remove ferromagnetic materials from the proximity of the magnetometers which are often mounted on booms outboard the wingtips.

A demand exists for high-resolution, smaller size surveys flown at low altitudes (Barnard, 2008). Sander Geophysics Limited (SGL) and Carleton University (CU), both located in Ottawa, Canada, started collaborating six years ago to assess the feasibility of unmanned aircraft systems (UAS) for such surveys. The SGL-CU collaboration, which involves teams of final-year undergraduate engineering students (aerospace, mechanical, electrical and computer systems) and graduate students from several disciplines, has resulted in the original design of an all-composite UAS suitable for high resolution geomagnetic surveys, the GeoSurv II, and the building of a prototype and a simulated UAS.

Design requirements

The primary requirements that must be demonstrated by the GeoSurv II UAS are:

- Airspeed range 60 to 100 kts (111 to 185 km/hr).
- Minimum flight altitude of 10 m AGL.
- Endurance of 8 hours at 60 kts.
- Area to be surveyed up to 10 by 10 km.
- Terrain following up to a gradient of 10%, both climb and descent.
- Autonomous operation; the UAS is to fly a pre-planned route; it will periodically send to the ground control station reports on progress and health status, as well as samples of the acquired aeromagnetic data. Also, the avionics system will provide obstacle detection and avoidance for stationary and moving obstacles. It will be possible to modify the mission from the ground control station.
- The baseline configuration of sensors is composed of two Cesium magnetometers at the wingtips and a fluxgate magnetometer in the fuselage.
- The payload mass is 9.1 kg; the payload is powered by the air vehicle electrical system.
- The uncompensatable magnetic field (noise) generated by the UAS shall not exceed 0.1 nT +/- 0.05 nT for fixed sources, and 0.01 nT +/- 0.005 nT for time-varying sources in a 0 to 5 Hz banwidth.
- The UAS will be launched by catapult and retrieved using a parafoil; however, a fixed landing gear system is currently provided for the prototype. It will be used during the initial flight testing and in surveys where an airfield is nearby.
- The UAS assembly and mechanical preparations for flight shall not exceed two hours.
- Crew shall not exceed two persons. It is envisaged that, in future, one crew would be able to control more than one air vehicle.

Construction and assembly of the GeoSurv II prototype

The GeoSurv II prototype developed in response to the above requirements is an all-composite aircraft of a twin-boom pusher configuration (Figure 1). The aircraft structure is modular: the wings, booms and empennage can easily be removed from the fuselage and the components fit in a trailer for transportation. The prototype is intended for flight testing and, thus, does not have full functionality, particularly with respect to avionics.

Carbon-epoxy composites are used throughout. They have been developed using a variation of a low-cost manufacturing method called Vacuum Assisted Resin Transfer Moulding (VARTM) (Maley, 2008). This method uses vacuum to draw polymer resin, in this case epoxy, through dry fibre laminated preforms in a single-sided mould. The components made using this process have very good strength, repeatability and low weight with excellent surface finish.

Where possible, mechanical components and fasteners have either been made from composites or from non ferrous materials (brass, austenitic stainless steel, titanium); however, some stock-bought components such as the engine and the servo-actuators for the flight control system do contain ferrous materials and, produce magnetic fields. Efforts have been made to maximize the distances between the magnetometers and such components. Also, the magnetic signature of various components as well as of the complete air vehicle will be measured in a magnetically "clean" facility in Ottawa as part of research to minimize their magnetic noise.

The fuselage structure (Figure 2) is a foam core sandwich made in an innovative single step manufacturing process, without mould. This structure has a floor panel part-way through height and a bulkhead divides the fuselage into two sections. The forward section is for mounting the components of the flight avionics including flight management computer, obstacle detection computer, autopilot, communications/telemetry system that will include Iridium set for the communications beyond the line of sight, radio control receiver and batteries. The radio control will be used primarily during the initial flight tests when the autopilot will function as a flight data acquisition system. The aft section contains the fuel tank and, in future, the parafoil. The nosecone and the upper fuselage hatches are non-structural, attached to the fuselage by polymer aerospace-grade fasteners. The lower hatch covers the full length of the fuselage, and is designed to carry the payload. Therefore, different lower hatches can be provided for mounting different mission equipment.

The GeoSurv II prototype was rolled out on 5 March 2010 (Figure 3). It has been undergoing ground tests in preparation for the taxi tests and the first flight, which will take place in the spring of 2010. It is important to note, however, that flight testing as well as survey operations will be restricted for several years due to the lack of a regulatory framework for routine UAS operations in Canada. Regulatory agencies (e.g. FAA and Transport Canada) currently do not allow the UAS operators to file (a flight plan) and fly (the mission). Instead, special permits are required such as Special Flight Operations Certificates in Canada. The main reason is safety concerns that will be

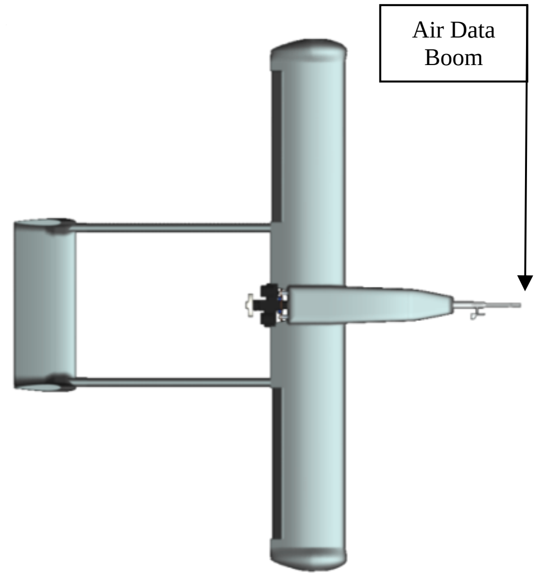

Figure 1: GeoSurv II prototype configuration. The wing span is 4.88 m. The length without the air data boom (to be used only in flight testing) is 4.27 m and the total height is 1.22 m. The internal combustion 2-stroke engine power is 30 HP and the design takeoff mass is 91 kg.

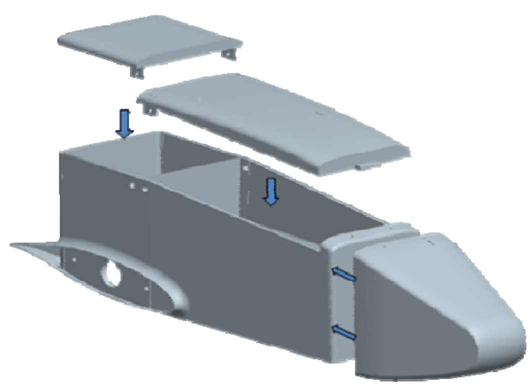

Figure 2: Fuselage structure. The structure is 1.1 m long with a cross-section 0.3 m wide by 0.39 m high. Its mass is 9.97 kg.

alleviated only once reliable “sense and avoid” systems are developed and integrated onboard UAS. A system of this type is being developed within this project.

Figure 3: GeoSurv II prototype, March 2010 (without wingtip magnetometer housings).

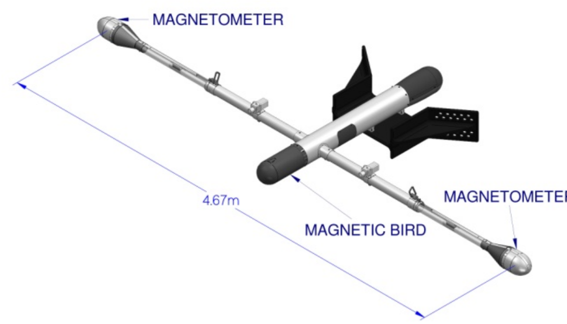

Figure 4: Engineering drawing of the simulated UAS. The simulated UAS is configured as a horizontal gradiometer with the cesium magnetometers spaced 4.67 m apart. Fixtures for component testing can be found internally and externally along the tubes making up the wings, and within the central body of the magnetic bird.

Aeromagnetic survey using a simulated UAS

A magnetic bird was modified to simulate the surveying capability of the UAS. This simulated UAS was designed to have a matching wing span with the same horizontal cesium magnetic gradiometer configuration as that of the UAS (Figures 4 and 5). Its purpose was twofold; to test and identify magnetic interference effects created by system components, and to approximate the data resolution of the UAS.

A test survey flown with the simulated UAS was completed in February 2010. A site that demonstrates a rapidly changing, geologically correlated, magnetic gradient was chosen for the survey. Located near the town of Plevna within the Central Metasedimentary Belt of the Grenville Province in Ontario, the site features a vertical similar fold of strongly magnetic metavolcanic rocks contacting weakly magnetic calcite marble. The fold occurs over an 8 km^2 area that is relatively pristine of cultural magnetic sources.

The survey was flown at an altitude of 50 m AGL with a traverse line spacing of 50 m and a control line spacing of 300 m. The surveying grid was designed to cross over the limbs of the vertical fold along a normal trajectory in order to sample the highest magnetic gradient. Since the fold occurs twice over the survey site, three different limbs of the fold are sampled along any traverse line.

Figure 5: Simulated UAS. The device has a centre body to house electronics; the centre body also has a stabilizer (perforated) at the aft end to ensure stable flight when suspended underneath a helicopter. The magnetometers are inside hemispherical fairings that are, in turn, fastened to conical adaptors and outer tubes made from carbon epoxy composites.

An example of the field data acquired by the simulated UAS along traverse line 1010 can be seen in Figure 6. The 50 m data (in black) and its upward continuation to 150 m (in blue) have been corrected for time and space lag. The data recorded by the Ontario Geological Survey (OGS) at an altitude of 150 m over the same line using a fixed-wing aircraft (in red) have been compensated and filtered by a reverse decorrugation filter followed by a Naudy non-linear low-pass filter (Ontario Geological Survey, 2003). Each data set has been corrected for IGRF and diurnal variations.

The high-gradient short-wavelength peaks that are sampled along traverse line 1010 provide a means to assess the ability of the simulated UAS to resolve features that would normally be captured only by a detailed ground survey. The simulated UAS data recorded at an altitude of 50 m shows a large increase in short-wavelength anomalies over the data sets calculated or recorded at an altitude of 150 m. The increase in resolution is such that individual features are now being resolved. This can be seen in Figure 6 near the large peak occurring at time equal to 170 s, where two short-wavelength peaks are emerging that were previously undetected or not well defined in the 150 m altitude data sets. The difference between the 150 m altitude OGS and upward continued simulated UAS data is small. The simulated UAS data can be seen to have shorter wavelengths incorporated into the signal. The simulated UAS survey, however, was conducted using a terrain drape, while the OGS survey was flown at a constant altitude. This may account for differences between the two data sets.

Conclusions and future work

The GeoSurv II UAS project recently reached two important and concrete milestones: a prototype is now ready for flight testing, and a simulated UAS is available for test surveys. Current research efforts are focusing on autonomous operations, obstacle detection, magnetic signature control of the UAS, and low cost composite construction. This research will move the UAS design towards operational status.

Acknowledgments

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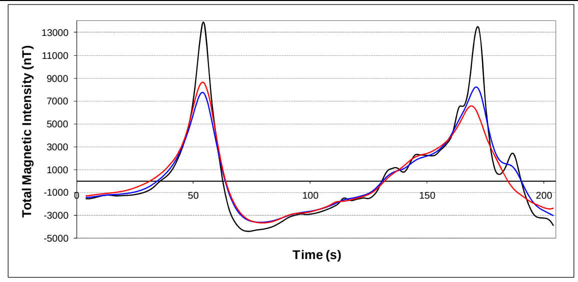

Figure 6: Total magnetic intensity data from traverse line 1010. Black line shows the simulated UAS measurements made at an altitude of 50 m. The blue line is the simulated UAS data upward-continued to 150 m. The red line is data resampled from the final 150 m altitude grid released by the Ontario Geological Survey in 2003.

EDITED REFERENCES

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