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A "MODEL" GEOPHYSICS PROGRAM

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ABSTRACT

In 1993, I tested a radio-controlled airplane designed by Jim Walker of Brigham Young University for low-elevation aerial photography. Model-air photography retains most of the advantages of standard aerial photography --- the photographs can be used to detect lineaments, to map roads and buildings, and to construct stereo pairs to measure topography --- and it is far less expensive. Proven applications on the Oak Ridge Reservation include: updating older aerial records to document new construction; using repeated overflights of the same area to capture seasonal changes in vegetation and the effects of major storms; and detecting waste trench boundaries from the color and character of the overlying grass.

Aerial photography is only one of many possible applications of radio-controlled aircraft. Currently, I am funded by the Department of Energy's Office of Technology Development to review the state of the art in microavionics, both military and civilian, to determine ways this emerging technology can be used for environmental site characterization. Being particularly interested in geophysical applications, I am also collaborating with electrical engineers at Oak Ridge National Laboratory to design a model plane that will carry a 3-component flux-gate magnetometer and a global positioning system, which I hope to test in the spring of 1994.

INTRODUCTION

Radio-controlled planes and helicopters have been available for many years, but the revolution during the last decade in miniature, low-power, electrical components and microprocessors, along with the improvements in Global Positioning Systems (GPS), make many new applications possible. To date, most of the work has been developing surveillance systems for the military (e.g. Finkelstein, 1989), the various branches of which have long-standing programs funding the development of unmanned vehicles, including model aircraft. Microairborne geophysics, however,

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represents a new and exciting field. In 1994, I hope to demonstrate a model airplane equipped with a lightweight, 3-component magnetometer, a microvideo camera, a global positioning system, and an altimeter.

At present, however, the electronics to telemeter the data from the magnetic sensors and GPS unit is still under development. Meanwhile the two Droop Snoops at ORNL are being used for low-altitude aerial photography. In my opinion, this application alone makes radio-controlled aircraft a valuable new tool for the geophysicist. In this paper I discuss primarily the results of low-altitude aerial photography at Oak Ridge National Laboratory (ORNL), then briefly describe current efforts to incorporate magnetic sensors, and elaborate on the potential advantages of using model aircraft to collect geophysical data.

Figure 1. Jim Walker holding his "Droop Snoop," a modified version of the commercially available "Senior Telemaster". The widened fuselage can hold a 35 mm camera (the lens projects slightly between the wheels).

EQUIPMENT

The two planes currently in use at ORNL were designed and built by Jim Walker at Brigham Young University. These "Droop Snoops" (Figure 1) are modified "Senior Telemasters", a model kit that can be obtained mail order or from a local

hobby shop. The modifications include: a wider fuselage to accommodate a 35 mm camera, a "Butterfly" wing, and the addition of carbon fiber to minimize vibration in the camera compartment. For an experienced builder the construction time is about 40 hrs, and the cost of the complete system including wood, epoxy, servos, engine, radio controller, flight box, and camera is about \$500-\$1000. The plane can be partially disassembled and packed into a shipping box small enough to check as luggage on a commercial airplane. Details of the construction can be found in Walker (1993).

The camera is an ordinary Ricoh KR10 single lens reflex, but other cameras can be used. The requirements are that the camera have automatic film advance, can be triggered electronically (a solenoid switch in the plane is triggered by radio from the ground), and is capable of shutter speeds at least as fast as 1/1000th of a second. These features are available in most moderately priced cameras. The fast shutter speed is essential to reduce blur created by the movement of the plane while film is being exposed. The "image motion problem", as it is referred to in the aerial photography literature, is the controlling factor which determines the resolution of the photograph. The Droop Snoop can fly as slow as 15-20 mph (slower when turned into a wind). At a speed of 15 mph the plane travels only about 0.26 inches in 1/1000th of a second, so the image quality is excellent.

Using a standard 35 mm camera has several advantages: they are easy to obtain and have serviced, film is readily available and can be processed at a 1-hr developer, and the image quality of enlarged photographs is superior to that of the smaller compact disc-film camera. A standard 35 mm camera is relatively heavy, however, and this affects the total payload. As currently designed, the Droop Snoop can carry about 4 lbs. In general there is a trade-off between payload and flight speed --- to carry more weight you have to fly faster (roughly 5 mph for each additional pound), which means less time over target and poorer picture quality.

PROCEDURE

A typical flight lasts 20-30 minutes, and consists of hand launching the airplane, flying it to an altitude of about 500 ft, making several passes over the target area, usually shooting a full 36 exposure roll of film to ensure coverage, followed by landing the plane in the nearest available clearing. Range is limited by the need for the pilot to be able to maintain eye contact with the plane, not by radio power. When the plane gets more than about a half mile away it can become difficult to tell which direction the plane is heading, or if it is gaining or losing altitude, with potentially unfortunate consequences.

Generally a crew of two suffices: a pilot to fly the plane and trigger the camera, and a spotter to launch the plane and notify the pilot when the plane is over the target area. It is essential to have an experienced model hobbyist on the team to pilot the plane and to make repairs. Some repair work is inevitable because paved runways or smooth grassy fields are the exception, rather than the rule. Typically the damage, if

any, is minimal and easily repaired in the field, or overnight if new parts must be fabricated. Even with a bad crash the expensive parts of the airplane -- the radio receiver, the servos, the engine -- are rarely damaged, so the cost of repairs depends on the amount of labor required, which is presumably less than the 40 hours required to build a new plane.

If the photographs are going to be scanned and digitally rectified to use with a geographic information system, then ground control points must be established in advance. With only a few ground control points the position and orientation can be computed; with more, the image can be "rubber-sheeted" to correct for camera angle and lens distortion. If a digital terrain model is available, then the distortion created by topography can also be removed, producing an orthonormal photograph. In most cases I have used the abundant groundwater monitoring wells on the Oak Ridge Reservation as my ground control points, but a global positioning system could be used in remote areas.

Figure 2. Solid Waste Storage Area 5. The study area was the Tritium seep areas in the southeast corner.

AERIAL PHOTOGRAPHY EXAMPLES

In the following sections I will present a number of case histories to illustrate some of the advantages and limitations of low-altitude aerial photography. For additional examples, see Walker (1993).

Solid Waste Storage Area 5

Solid Waste Storage Area 5 (SWSA 5), a burial ground located on the Oak Ridge Reservation, in Oak Ridge, Tennessee, was used to dispose of low-level radioactive waste from 1959 to 1973 (Figure 2). Much of the waste was buried in unlined trenches, which are reported to be 10-15 ft deep, 10-12 ft wide, and 40-500 ft long. The precise location of many of these trenches is now uncertain; so I chose this site to test if the low-altitude aerial photography system could be used to detect trench boundaries. I focused on a subarea in the southwest corner of SWSA 5 where there are several known groundwater seeps releasing tritium into a nearby creek.

The photographs clearly show the outline of several of the trenches (Figure 3).

Apparently, as the trench fill settled, a small depression formed over the trench that both acts as a rain water catchment and prevents the mower blades from cutting as close to the ground. The

result is greener grass over the trenches. This disturbed vegetation pattern is difficult to see in ground based photographs because of the mowing patterns and because one is simply too close to get a proper perspective.

Figure 3. The grass grows greener over the waste trenches. A cross constructed of 1 ft square floor tiles and an adjacent arrow provide information on scale and magnetic north.

Hydrofracture Deep Waste Injection Facility

The SWSA 5 case study demonstrates how aerial photography can be used to identify vegetation patterns not easily perceived by an observer on the ground. The low cost associated with taking aerial photographs using a model airplane makes it

economical to show changes over time by flying repeated missions over the same site: to capture leaf-out in the spring, to detect changes in sediment transport patterns after storms, or to document changes at a waste site undergoing remediation. More generally, aerial photographs also make an excellent addition to a report simply to show the area of investigation, the layout of geophysical survey lines, or the current land use (possibly contrasted with historical photographs).

In this example, seismic and borehole geophysical investigations are planned for an old waste injection facility near SWSA 5 where low-level radioactive waste was mixed in a concrete grout and injected under pressure deep into the bedrock. Unfortunately, not all of the grout set properly; analysis of groundwater samples from nearby monitoring proved that radionuclides are leaching away from the site. An aerial photograph taken with the Droop Snoop (Figure 4) shows the size of the facility, the layout of the roads and buildings, and the deteriorating condition of some of the old storage tanks (lower left corner). The image quality is excellent: drainage ditches, mowing patterns, even individual power lines can be seen on the original photograph. This photograph will undoubtedly be included in a future report when the geophysical investigations are complete.

Figure 4. ORNL Hydrofracture Facility. Low level radioactive waste mixed with concrete was injected under high pressure hundreds of feet below the surface.

DISCUSSION

Radio-controlled aircraft can be used to take inexpensive, high-quality, aerial photographs. This, by itself, represents an important new tool for environmental site characterization. For the geophysicist, however, the interesting questions remain: First, can the methods used in conventional airborne geophysical surveys can be adapted to small, radio-controlled aircraft? The answer is that it is only a matter of time. The second question is harder: What is gained?

Aerial geophysics developed predominantly as a tool for mineral exploration. There the objective was to provide rapid reconnaissance of hundreds of square miles, generally followed by land-based geophysical surveys of promising anomalies. Recently, traditional aerial methods have been used with success for environment site characterization (Doll et al., 1993, Smith et al., 1992), but many environmental sites are too small to justify the cost associated with helicopter-based geophysics. For sites smaller than a few hundred acres, cheaper and higher-resolution data can be obtained using land-based methods.

Because burial records are often poor or non-existent, the usual reason for performing a magnetic or electromagnetic surveys is simply to determine the extent of a burial ground, or even whether there is any buried waste present. It is not unusual to collect magnetic data for a 50-acre site and discover later that the drums were all buried in one small subarea. One can reduce the number of measurements required to screen such a site by starting with a coarse measurement grid and refining it, but a quick reconnaissance tool would be preferable. This is the answer to the second question, the potential niche I envision for a radio-controlled helicopter or airplane equipped geophysical sensors. In addition to rapid coverage, a miniature airborne geophysical system would be able to fly over rugged or uncleared terrain, and survey areas with dangerous levels of contamination.

My next step will be to mount a microvideo camera and a small, 3-component, fluxgate magnetometer on a plane, and telemeter live video and magnetic data to a base station. To process the magnetic data will require good positioning information. Initially, the video data in conjunction with ground control points can be used to reconstruct both position and height, but eventually I hope to use a differential GPS for xy-positioning and a precise altimeter (acoustic, laser, and radar are all being considered) for height.

Model helicopters, blimps, and other miniature aerial platforms merit consideration. Over the next year I will be reviewing the work of military and civilian agencies to learn more about the possible applications of their ongoing work in unmanned aircraft to environmental surveys. Special attention will be paid to low-cost systems; despite the current efforts within the military to develop "dual use" technology, not many of the military contractors are used to designing instruments priced to sell to geophysicists. Much of the expensive technology being tested,

however, is part of an effort to develop advanced autopilot and telemetry systems to allow the systems to be used with minimal training. The cost will eventually come down, as they have with global positioning systems. Microairborne geophysics has a bright future.

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