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## BIRD-BORNE SATELLITE TRANSMITTER AND LOCATION PROGRAM

Several birds carrying APL-developed transmitters have been tracked by satellite with good results, but more work should be done to develop lighter, more reliable hardware.

### INTRODUCTION

An APL-developed bird-borne transmitter for tracking large migratory birds by satellite was discussed in an earlier article.<sup>1</sup> The results from field tests conducted with wild birds are summarized here.

Satellite transmitters can fill a large gap in the techniques used to track birds. Traditionally, birds have been tracked with small, low-power transmitters with typical ranges of several kilometers. With those transmitters, birds are located by finding the direction of the strongest signal at several locations and then triangulating. Although very time-consuming and limited to accessible areas, the method offers precise data about habitat and migration routes. At the other extreme, leg-band returns provide only limited data on habitat and migration routes and nothing on birds that travel long distances over water or through uninhabited areas.

By using satellites to track birds, information can be obtained on long-distance bird migrations anywhere in the world, and potentially hundreds of birds can be tracked for a year or more. Although effort is required to catch the bird and to attach the transmitter, as is required for more conventional marking methods such as leg banding or short-range transmitters, data on bird movement can be obtained without arduous field work. Additional information on bird activities can be obtained by placing sensors on the transmitters. A transmitter was needed that would weigh under 200 grams and could transmit signals indicating its location once a day for six to eight months. Birds could be followed for one complete migration cycle so that the flyways birds use during migration could be identified.

### DESIGN OF APL TRANSMITTER

The transmitter was designed to work with the ARGOS system, a Doppler positioning system similar to the Navy Transit satellite system, carried aboard

the National Oceanic and Atmospheric Administration's TIROS-N satellites. However, it differs from Transit in that the transmitters are on the ground (or on birds) and the receiver is in the satellite. Each transmitter's unique identification number and data from sensors are encoded in the transmitted signal by phase modulation; these are decoded by the satellite. The transmitter frequency as measured at the satellite is Doppler shifted by the satellite motion; measured frequency shifts are used by a central processing facility (located in France) to determine the transmitter position. Later, the transmitter location and other data are disseminated via a computer and telephone network to owners of the transmitters. Although the ARGOS system was designed to track and gather weather data from buoys and balloons, it can be used to track animals just as well.

The size and weight of the transmitter are the most critical parameters for any device being carried by a bird. However, the task of keeping the weight low for the satellite transmitter is very difficult because satellite tracking places stringent specifications on the design that are not present for traditional bird transmitters. The transmitter must radiate a signal many times stronger than conventional transmitters do, in order to be received by the satellite. In addition, for Doppler positioning to work, the transmitter crystal oscillator must be several orders of magnitude more stable than that in a conventional wildlife transmitter. Encoding the transmitter identification number and sensor data in the signal is also a complication not usually found in conventional transmitters.

Two significant features helped to minimize weight. Solar cells charge small nickel-cadmium batteries which, in turn, power the transmitter. Solar power provides a potentially much longer lifetime than would be possible with nonrechargeable batteries of the same weight. A small temperature-compensated crystal os-

cillator was used for the frequency standard; the stability of the oscillator gives locations accurate to about 1 kilometer.

The total weight of the transmitter is about 170 grams; however, the design has some drawbacks—the weight, together with shape, will have negative effects on a bird's ability to fly. We limited our activities to large birds so that the transmitter weight was less than 5 percent of the bird's weight. Some transmitters were equipped with a microprocessor and temperature, voltage, and motion sensors.

### FIELD TESTS

Tests of the transmitter were conducted in the laboratory and on captive and sedentary birds<sup>1</sup> before the transmitter was field tested on wild birds. Tests under realistic conditions were not easy. It is difficult to catch birds—and even more difficult to catch the same bird again if something goes awry. In addition, not many birds can carry a 170-gram load without long-term adverse effects.

### Swans

Two North American species were chosen for the first tests: trumpeter swans and tundra swans. These are large birds, typically 6 to 9 kilograms in weight, that migrate long distances over little-known routes. Trumpeter swans migrate to the Pacific Northwest; tundra swans (formerly known as whistling swans) migrate over Canada to winter in the mid-Atlantic states.

Swans breed on small ponds in Alaska. They can be easily captured during late July or early August because the birds molt (lose old flight feathers and grow new ones) and are flightless. An expedition consisting of three APL staff members and two sponsors was mounted in early August 1984 in an area about 50 kilometers west of Fairbanks, Alaska, to capture trumpeter swans. Three team members also flew to the north slope of Alaska to capture two tundra swans on the Colville River delta.

In order to capture a swan, a small pontoon plane with two or three people aboard lands on the pond. Holding a long net, one person stands on a pontoon; the pilot controls the plane and chases the bird around the pond until it is caught. The bird is transported to shore where it is weighed and measured, a standard leg band is applied, and the transmitter is attached. A neck collar is placed on the bird to enable identification from afar. Gentle handling of the bird is necessary.

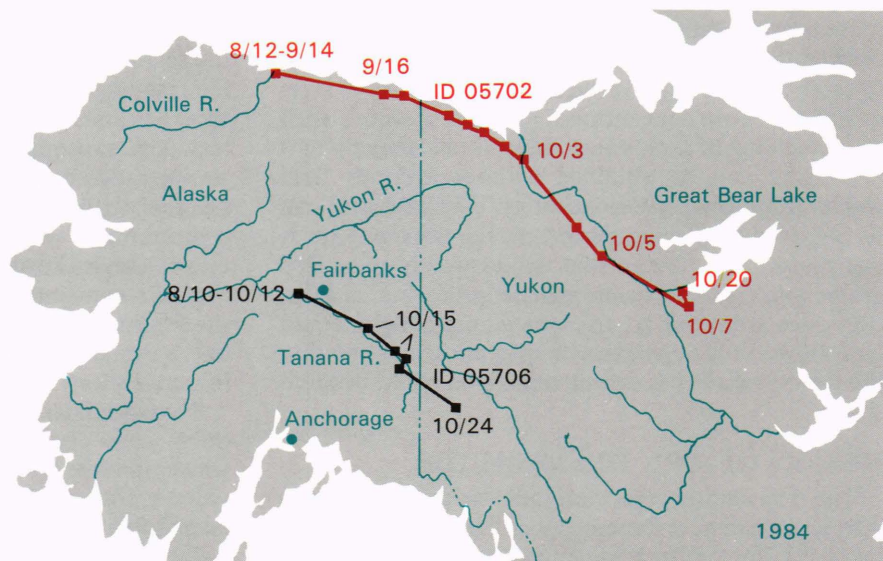
Transmitters were placed on the two trumpeter swans and the two tundra swans; a fifth transmitter was placed on a cygnet by U.S. Fish and Wildlife personnel. One transmitter failed shortly after our return to Maryland; it could not be recovered because by this time the swan was able to fly.

For several months after the transmitters were attached, the birds remained on the ponds where they were captured and their position was watched closely. Movement of the northern birds was first evident in mid-September. As the ponds froze, they moved to the small river channels and then to the main stream. The southern birds left their nesting ponds in October. By that time, the weather was quite inhospitable.

One of the tundra swans (identification number 05703) was followed for several weeks by satellite. It moved about 50 kilometers up the Colville River and then contact was lost. The other tundra swan (ID 05702) left the river delta and traveled eastward along the coast, thereby avoiding the Brooks mountain range. For the next several weeks, it traveled along the Mackenzie River, stopping for several days at various points. However, after it reached an area just south of Great Bear Lake (1500 kilometers from the Colville River delta), it remained nearly stationary until transmissions stopped (Fig. 1). Judging by the lack of movement and the severe weather reported south of that area, we believe that the bird died.

The trumpeter swans captured near Fairbanks flew southeast up the Tanana River. The cygnet (ID 05708) stopped after flying only 80 kilometers, but the adult

**Figure 1**—Map of Alaska and North-western Canada showing the routes of two swans tracked via satellite. The transmitter numbers are used by ARGOS to identify the transmitter that is being received. A tundra swan, ID 05702, and a trumpeter swan, ID 05706, migrated into Canada before transmissions stopped.



(ID 05706) flew into Canada (a distance of 680 kilometers, see Fig. 1). The last several positions from each bird came from the same locations.

Confirmation that the cygnet had probably died came the following spring. On May 7, 1985, we received reports through ARGOS of telemetry from the transmitter on the cygnet. No locations were provided by ARGOS for the first four days (this occurs because the Doppler frequencies have excessive scatter); however, we could determine from the time the transmissions were received and from the satellite orbit that the transmitter was located near Fairbanks. Later transmissions received by ARGOS confirmed that the transmitter was located near the last position of the bird the previous fall. Because snow was melting rapidly in the area, we concluded that the bird had died and had been buried by the snow until spring. After the snow melted, the solar cells charged the battery. The transmitter could not be found because of the large scatter (about 700 meters) in the transmissions; the area is a rather featureless bog that is difficult to search. After several weeks, transmissions stopped. The bird was never found.

### Bald Eagle

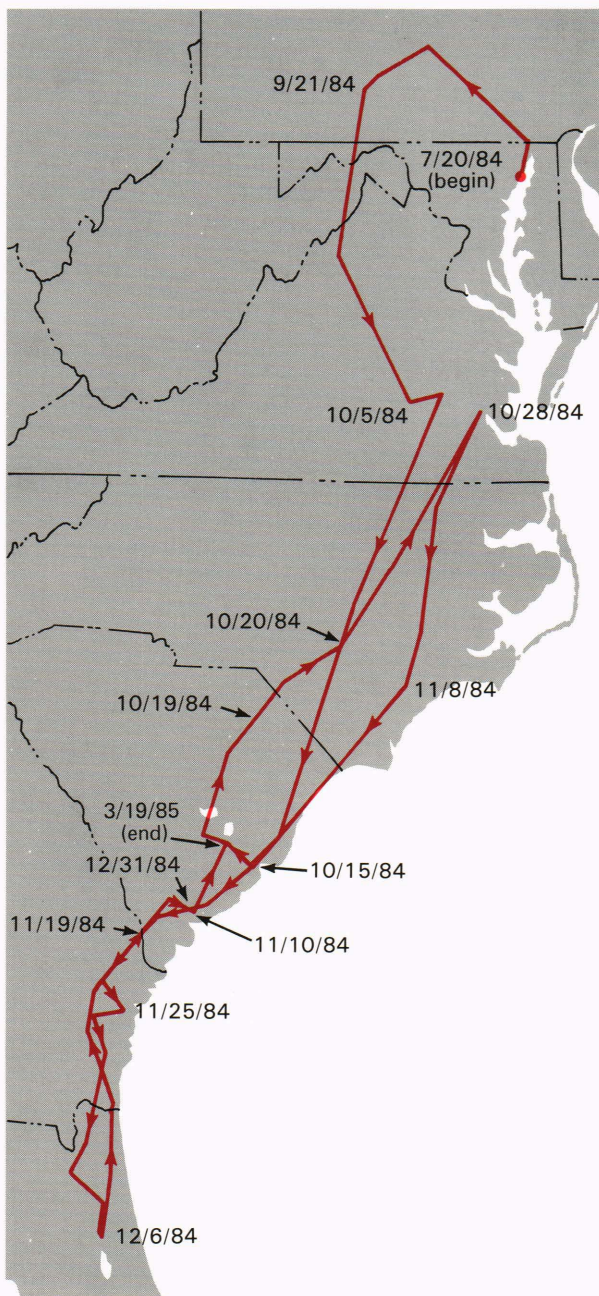
We had more success with a bald eagle. On July 21, 1984, a sub-adult male bald eagle was captured in northeast Maryland, and a satellite transmitter was attached (ID 05704). The eagle remained in the Chesapeake Bay area for several months before flying to Pennsylvania. Then, throughout the fall of 1984, it flew into Virginia, to the Carolinas, back to Virginia briefly, and then to Florida (Fig. 2). It then returned to South Carolina and remained in the vicinity of Colleton County until March 1985 when transmissions stopped. The eagle had been banded in a nest in that region four years previously.

Unfortunately, we were unable to recover the transmitter at the end of its nine months of life. However, the extent of the area covered by this eagle and the specific habitats it used provided new insights into the lives of these birds.

### Southern Giant Petrels

Our experiences with the transmitters on the swans and the eagle convinced us of the need for better candidates for testing: a species that is (a) easy to catch, (b) easy to catch a second time, and (c) large enough to carry the transmitter comfortably. Southern giant petrels were found to be good candidates for transmitter studies. They are very large (typically weighing more than 5 kilograms) and are relatively easy to catch on the nest every year. Although their travel routes are poorly known, they travel large distances in the south polar region.

During early January 1985, transmitters were taken to Palmer Station in Antarctica. Six birds were harnessed with transmitters (see Fig. 3), observed during the month, and followed by satellite for about two months. Figure 4 shows the movements of two of them (ID 05709 and 05712). The bird with transmitter 05709



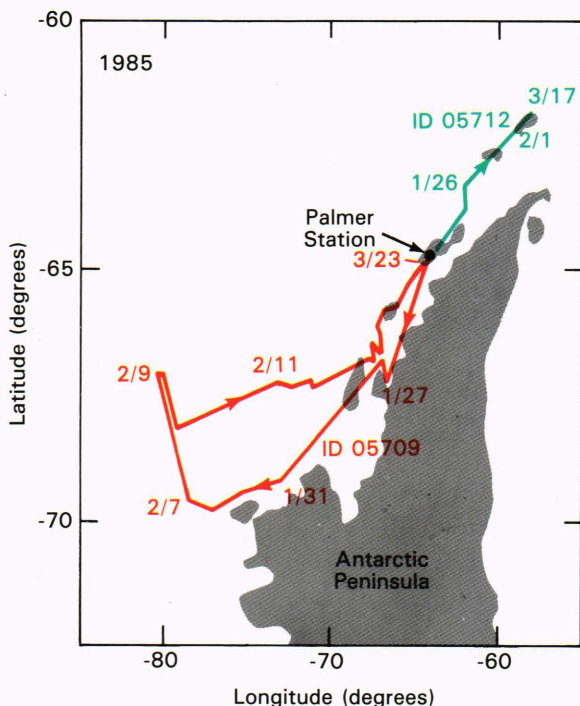
**Figure 2**—Route of a bald eagle with an APL transmitter for the period July 21, 1984, to March 19, 1985. The eagle was banded in South Carolina as a fledgling and was caught four years later on the Chesapeake Bay, when the transmitter was attached. It was in South Carolina when the transmitter stopped.

traveled the greatest distance (over 2000 kilometers), flying out into the South Pacific Ocean west of the Antarctic Peninsula. All the other birds flew up or down the peninsula, but only 05705 and 05714 appeared to return frequently to their nests.

The reasons the Antarctic transmitters stopped transmitting are not known. As winter approaches during March, the number of transmissions would decrease. We suspected battery and power control cir-



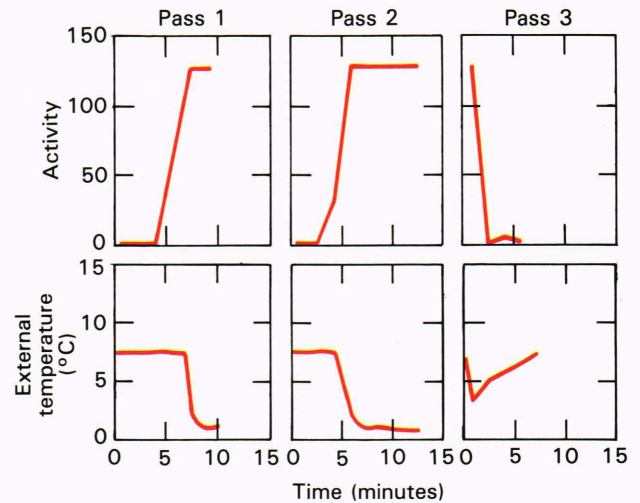
**Figure 3**—Southern giant petrel with APL transmitter attached. This species is similar to the albatross, soaring on long narrow wings and feeding from the ocean.



**Figure 4**—Map of the Antarctica Peninsula, below Chile, showing the routes of two southern giant petrels tracked by satellite during early 1985. The petrel with ID number 05709 traveled over 2000 kilometers in 30 days.

cuitry malfunction as one likely cause of transmitter failure. More detailed studies later indicated that, at very cold temperatures, the battery became unreliable, and the charge control circuitry did not charge the battery properly or switch the transmitter on at the correct voltage. Scientists at Palmer Station did not locate any of the birds in early 1986.

Because none of the birds returned, it is clear the effect of the transmitter on bird behavior is apprecia-



**Figure 5**—External temperature and motion data received from ID number 05714 on a giant petrel for three successive passes. The external temperature sensor is at the front of the transmitter and is covered by feathers when the bird is stationary. The motion sensor counts the number of movements during a brief period. The first two frames indicate that the bird took flight midway through the satellite pass because the temperature plummets and the motion sensor saturates.

ble. The effects of carrying a transmitter are being studied intensively. Weight may be only one aspect of the problem; other effects such as heat loss or abrasion of the bird's back by the package or of the wings by the harness could also play a role.

Several transmitters incorporated sensors to provide information about the birds' movements. Our transmitters had eight telemetry channels, one of which was used as a reference to monitor long-term drift. Four were temperature channels (one external and three internal), two were voltage channels (solar array and battery), and one indicated a reading that alternated between an activity sensor and a time-since-switch-on counter. Most channels monitored transmitter performance; however, the motion and external temperature channels could be used to infer bird behavior.

Figure 5 presents data from the motion and external temperature channels for three consecutive satellite passes. The external temperature sensor, mounted on the front of the transmitter, gave high readings when the bird was resting because its neck feathers would cover the sensor. There was little or no activity during that period. The readings changed dramatically when the bird took flight during the first two passes; the temperature dropped and the activity saturated the sensor, which gave a maximum activity count of 127.

### SUMMARY

The test results were encouraging in some respects but suggested areas for further study and development. Birds can be tracked successfully by satellite. Table 1 summarizes the period of time we have followed individual birds and the approximate distances they have traveled. However, a number of issues need to be ad-

**Table 1**—Summary of time periods birds have been followed and approximate distances traveled.

<i>Bird</i>	<i>Trans. No.</i>	<i>Dates</i>	<i>Distance (km)</i>
Bald eagle	05704	Jul 21, 1984 — Mar 19, 1985	4554
Trumpeter swan	05700	Aug 9, 1984 — Aug 29, 1984	24
Trumpeter swan	05706	Aug 9, 1984 — Oct 21, 1984	685
Trumpeter swan	05708	Sep 21, 1984 — Oct 16, 1984	191
Tundra swan	05702	Aug 13, 1984 — Oct 20, 1984	1506
Tundra swan	05703	Aug 14, 1984 — Sep 15, 1984	127
Southern giant petrel	05701	Jan 26, 1985 — Feb 2, 1985	188
Southern giant petrel	05703	Jan 19, 1985 — Mar 19, 1985	1082
Southern giant petrel	05705	Jan 28, 1985 — Mar 8, 1985	1150
Southern giant petrel	05709	Jan 21, 1985 — Mar 17, 1985	2320
Southern giant petrel	05712	Jan 21, 1985 — Mar 17, 1985	639
Southern giant petrel	05714	Jan 26, 1985 — Mar 16, 1985	1730

ressed before this method is applied to a large number of species.

The major transmitter problem was reliability. Transmitters often failed prematurely, sometimes before they could be placed on the birds. Most of the reliability problems have been with the batteries. We have continued to refine our power control design and battery requirements.

Another problem appears to be the effect that the transmitters have on the birds. Tracks of the swans indicate that the birds died while migrating. We can speculate as to the causes—possibly the weight of the transmitter, the effects of the harness on the flying ability of the birds, and heat loss caused by the package pressing against the bird. However, because we have not recovered even one transmitter, we can only guess at the reason for those failures. While swans have been tracked in the past (including previous research at APL<sup>2</sup>), few data are available concerning harness reliability. It is also not known whether some of the birds (particularly the swans) succumbed to natural causes such as early severe weather.

We have pioneered bird tracking by satellite. Satellite transmitters are far more complex and therefore

less reliable than conventional tracking transmitters; considerable effort must go into weight reduction and reliability engineering. In addition, thorough testing on various bird species is required to finalize package and harness designs in order to minimize effects on bird behavior and prolong survival.

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- <sup>2</sup>W. A. Good and J. W. Hamblen, "How High Does the Whistling Swan Fly?" *APL Tech. Dig.* 10, 2-10 (1970).

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#### THE AUTHORS

THOMAS E. STRIKWERDA (right, front) joined APL in 1981 as a senior staff physicist in the Space Analysis and Computation Group. He was born in Grand Rapids, Mich., in 1948. He received a B.S. degree in physics from Calvin College in 1971 and a Masters degree (1974) and Ph.D. degree (1977) in astronomy from the University of Virginia. After leaving the university, he was a research associate and then an assistant professor at Virginia Polytechnic Institute and State University in the Engineering Science and Mechanics Department.

In addition to his work on the Bird-Borne Transmitter, Dr. Strikwerda has recently worked on planet-tracking algorithms and astrometry error analysis for the Hubble Space Telescope.

He is a member of the American Astronomical Society, the American Institute of Aeronautics and Astronautics, and the Society of Photo-Optical Instrumentation Engineers. For fun, he goes birding.

MARK R. FULLER (left, standing) is a research biologist at the Patuxent Wildlife Research Center (U.S. Fish and Wildlife Service). He was born in Minneapolis in 1946 and received a B.S. from Colorado State University, an M.S. in zoology from Central Washington State University, and a Ph.D. in ecology and behavioral biology from the University of Minnesota. Dr. Fuller's research involves studies of the population status and habitat requirements of migratory birds, specializing in birds of prey. Dr. Fuller uses telemetry to study the migratory pathways and to determine the habitat requirements of birds.

WILLIAM S. SEEGAR (center, standing) was born in Baltimore in 1948. He received a B.A. in biology from the College of Wooster and a Ph.D. in pathobiology from The Johns Hopkins University, School of Hygiene and Public Health. He was awarded a NATO

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PAUL W. HOWEY (right, standing) joined APL to work on the Bird-Borne Transmitter program in 1983. He had previously developed a miniature remote-sensing and radiotelemetry system to study microclimates at the University of Bath (U.K.), where he received a Ph.D. degree in 1982. Paul was born in 1952 in Newcastle-upon-Tyne and from an early age has been interested in things that "work," which eventually led him to study the life sciences at the University of Liverpool where he specialized in neurophysiology. He received a B.S. degree there in 1974. In his free time, he designs and builds miniature radio and electronic control systems for model helicopters and aircraft.

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Institute of Technology and the University of Maryland. He worked at Rohm and Haas Co. in Huntsville, Ala. (1952-54), and at the Armour Research Foundation of the Illinois Institute of Technology during 1954-57. Mr. Black joined APL in 1957 and the Space Department in 1958. During 1970-71, he was a Parsons Fellow in biomedical engineering.